

Commerce Spectrum Management Advisory Committee (CSMAC) Working Group (WG) 3 Phase 2 Study Summary

May 29, 2013

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This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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14. ABSTRACT The Department of Commerce National Telecommunications and Information Administration (NTIA) identified the Commerce Spectrum Advisory Committee (CSMAC) as the primary forum to facilitate technical discussions between industry and federal agencies regarding repurposing spectrum for commercial use. CSMAC Working Group 3(WG3) is focused on sharing of the 1755-1850 MHz band between federal satellite operations (SATOPS), DOD electronic warfare and commercial mobile wireless (MW) broadband. CSMAC WG3 and the DOD Chief Information Officer requested that The Aerospace Corporation provide a characterization of government satellite operations at specific ground stations with the potential to impact MW operations in the future. The report provides estimates of the areas potentially impacted by government usage of ground to satellite links from the AFSCN and other government sites and assesses the feasibility of government and commercial sharing of the 1755-1850 MHz band. The analysis involves an assessment of radio emissions and their effect upon terrestrial mobile wireless providers within the vicinity of government ground sites that are potentially subject to interference. The analysis provides contour maps of the various power levels for differing scenarios at these locations. The limitations of the use of various models to simulate power profiles were described and their results were based on general usage not actual operational scenarios. The study identified the need to assess actual ground site parameters for potential impacts and noted that regulatory provisions should allow for potential changes in government mission requirements including the possibility of greater satellite contact times, higher power levels at existing sites and the addition of new sites. The information is provided for estimating purposes only and is not intended to be representative of actual ground site operating parameters in the future.				
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Foreword

This report was originally released as TOR-2013-00257. It has been reissued as a technical report (TR), with distribution expanded to public release.

Technical Report

Foreword

The concepts and analysis provided in this report are intended for Government and Commerce Spectrum Management Advisory Committee (CSMAC) discussion purposes only.

The information is provided for use in developing estimates only and is not intended to be representative of actual ground site operating parameters in the future.

Government operational information for the 1755-1850 MHz band studied in this report has been summarized and enveloped to avoid presenting individual program or ground site information.

Outline

- Executive Overview
- Purpose
- Methodology
- Results
- Summary
- References
- Appendix
 - A. Study Results*
 - B. Technical Rationale*

Executive Overview

The Department of Commerce National Telecommunications and Information Administration (NTIA) identified the Commerce Spectrum Advisory Committee (CSMAC) as the primary forum to facilitate technical discussions between industry and federal agencies regarding repurposing spectrum for commercial use. CSMAC Working Group 3 is focused on sharing of the 1755-1850 MHz band between federal satellite operations (SATOPS), DOD electronic warfare and commercial mobile wireless (MW) broadband. CSMAC Working Group 3 and the DOD Chief Information Officer (DOD/CIO) requested that the Aerospace Corporation provide a characterization of government satellite operations at specific ground stations that could potentially impact commercial MW broadband operations in the future.

Aerospace analyzed government uplink emissions from three Air Force Satellite Control Network sites (New Hampshire Station, Vandenberg Tracking Station, Hawaii Tracking Station), two Navy sites (Blossom Point and Laguna Peak Tracking Station) and the NOAA Fairbanks Alaska site. The analyses made use of NTIA's Irregular Terrain Model (ITM) associated with the NOAA/NGDC GLOBE terrain database for propagation prediction in conjunction with historical SATOPS information. The results are presented on maps in the vicinity of the selected SATOPS locations to display, as a function of distance and azimuth from the SATOPS sites, contours of two parameters: 1) the predicted peak received power levels (for median values of path loss), and 2) the probability over time that the received power does not exceed the selected MW interference threshold (for median values of path loss).

The results of modeling transmitted radiation as a function of distance from each site with various attenuation scenarios are presented. Potential exceedence of the standard LTE threshold is also presented for each case. In addition, estimates of site usage based on satellite contact parameters are provided. The presentation format for the simulation outputs was specified by CSMAC Working Group 3. Uncertainties associated with each of the models used (mission astrodynamics, power, path loss, terrain, and probabilities) are described, including propagation variabilities and approximations of the terrain data. The models have inherent limitations such as lack of vegetation information, so the data should not be construed to be actual power levels of the AFSCN or other sites.

In summary, this report provides estimates of the areas potentially impacted by government radio emissions from selected ground facilities. The information is provided for estimating purposes only and is not intended to be representative of actual ground site operating parameters in the future.

Purpose

- The purpose of this study is to provide a characterization of Air Force, Navy and NOAA uplink Satellite Operations (SATOPS) in the band 1755-1850 MHz and to estimate areas in the vicinity of government ground sites that are potentially subject to interference
- The intended use of this study is for transmittal to the Commerce Spectrum Advisory Committee Working Group 3
- Information should be used for determining the next steps of evaluation and not for final decisions regarding spectrum sharing within bands

Methodology

- Computer Tools Used in Study
 - *The Power Model is a specialized scenario using the Aerospace SOAP Model (Ref. 1) that computes Radio Frequency Interference (RFI) power received by a cellular base station (receiver) when SATOPS antenna pointed in each Azimuth/Elevation (Az/El) cell*
 - *The Path Loss Model computes RFI reduction at cellular base station (receiver) as input to the Power Model. Consists of NTIA Irregular Terrain Model (Ref. 2) with GLOBE Terrain Data Base (Ref.3).*
 - *The Aerospace Astrodynamics Mission Model computes for each SATOPS site, the transmit minutes per year (average) in each Az/El cell*
 - *The EXCEL Combiner Model computes for a cellular base station (receiver), RFI power histogram and “probability” of RFI power not exceeding the receiver threshold of harmful interference*
- The accompanying chart shows the four major computer tools used in this study, and the data flows between them

Methodology

Calculating Commercial Base Station Received Interference Resulting from a Specific Government SATOPS Antenna

RFI POWER MODEL

**CELLULAR RECEIVER
AT 37.55N, 90.15 W**

AZIMUTH \ ELEVATION	ELEVATION							
	0-1°	1-2°	2-3°	179-180°
AVERAGE REC'D POWER								
0.0-0.2°								
0.2-0.4°								
0.4-0.6°								
...								
45-46°								
...								
89-90°								

ASTRODYNAMIC MISSION MODEL

AZIMUTH \ ELEVATION	0-1°	1-2°	2-3°	179-180°
MIN PER YEAR								
0.0-0.2°								
0.2-0.4°								
0.4-0.6°								
...								
45-46°								
...								
89-90°								

PATH LOSS MODEL

**CELLULAR RECEIVER
AT 37.55N, 90.15 W**

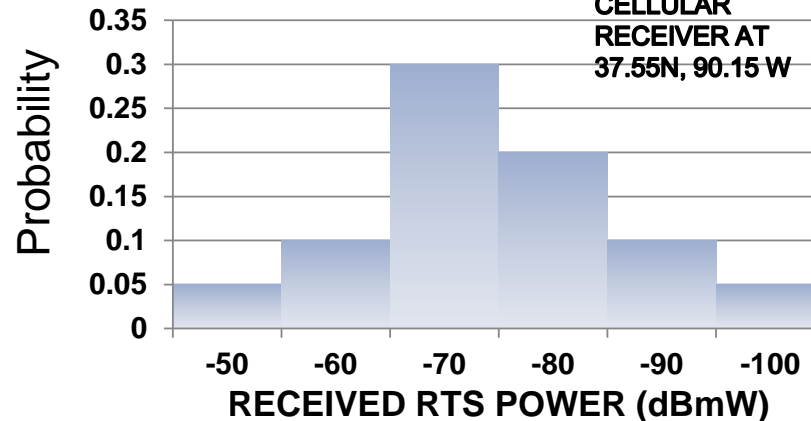
NTIA/Irregular
Terrain Model
(with GLOBE
terrain database)

Rec'd Power

Pointing
Minutes/Year

EXCEL COMBINER

**CELLULAR
RECEIVER AT
37.55N, 90.15 W**



Methodology

Propagation Models

- No single propagation model is best suited for all purposes
 - *Some models are conservative regarding predicting interference (i.e., lead to predicting more interference than would really occur)*
 - *Other models are conservative towards identifying low signal levels (i.e., lead to predicting lower received power than would really occur)*
- Models also have varying degrees of accuracy
- While there are varying degrees of uncertainty associated with any model, these types of models are typically applied in spectrum management studies

Methodology

Theoretical Bases and Assumptions

- Path Loss
 - *Each path loss is the median value loss computed by the Irregular Terrain Model (the NTIA path loss model adopted by CSMAC) using the “Globe Database” of terrain elevation maps*
- Pointing Minutes
 - *Output of orbital simulation Aerospace Astrodynamic “Mission Model” for each SATOPS site*
 - *The minutes of radiate time is the sum of the contributions of all satellites in the “Mission Model” in the spectral band of interest that operate in the band of interest, distributed over all Az/EI cells above minimum allowable elevation angle*
 - *Radiate time amounts to a fraction of the total contact time*
 - *Contact start and end times are derived from recorded experience*
 - *Radiate start time is randomly distributed uniformly over contact time*

Methodology

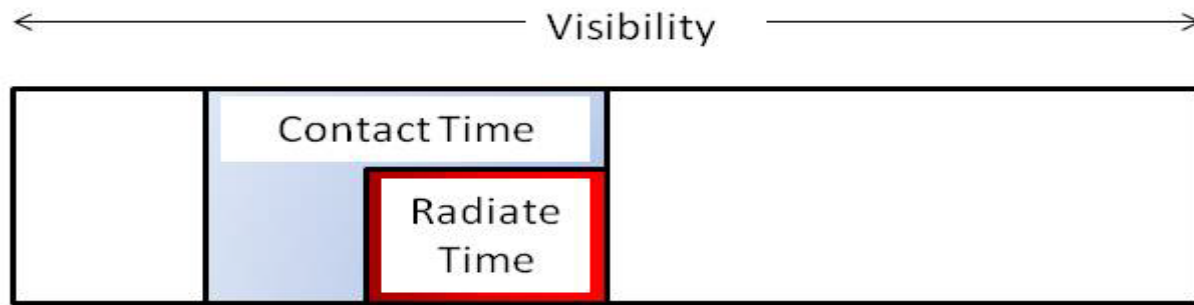
Theoretical Bases and Assumptions (cont.)

- Received power histogram for antenna sites
 - *For single antenna sites, each power level, the “probability” is defined as the sum of the “Mission Model” Az/EI cell values (which are the annual transmit minutes for each Az/EI) divided by yearly minutes for all the same Az/EI cells corresponding to the received power level*
 - *For sites with 2 or more antennas, “probability” is defined as percent time (all site antennas) below threshold RFI level, less percent time of overlap (i.e. simultaneous radiation)*
- Threshold Exceedance Contours
 - *The probability that the RFI doesn’t exceed threshold power level, assuming that the path loss is, in fact, the median value given by the ITM model (see Model Limitations)*
 - *Is the complement of the sum of probabilities for received power levels exceeding the threshold level*
 - *The “LTE Threshold” is assumed to be -137.37 dBW or (-107.37 dBm) using CSMAC WG-1 documented values (Ref. 4)*

Methodology

Theoretical Bases and Assumptions (cont.)

- Contact Time
 - *Based on statistical records averaged for one year for the AFSCN sites and estimated for non-AFSCN sites*
 - *Actual radiation time is less than visibility time as depicted in the figure below*



- *Note that publicly available ITU registration data may be used to estimate visibility time, but does not indicate actual radiation time*
- *There is sometimes flexibility in contact time scheduling; many times there is not flexibility*

Methodology

Model Uncertainties

- Major factors constraining utility of analysis results and conclusions
 - *Uncertainty of applicability of ITM model to urban propagation*
 - *Uncertainty inherent in use of ITM model without ground truth*
 - *Unknown impact of input variables on ITM model outputs*
- Minor factors
 - *Underestimation of SATOPS Radio Frequency Interference (RFI) due to distribution of radiate time*
 - *Underestimation of SATOPS RFI due to not accounting for elevation angle to first path obstruction*
- Unknown factors
 - *Possibly inadequate terrain data resolution*
 - *Possible electromagnetic environment factors to which ITM is not sensitive*
 - *Uncertainty in the effect of receiver site constraints*
 - *Changes in the terrain*

Methodology

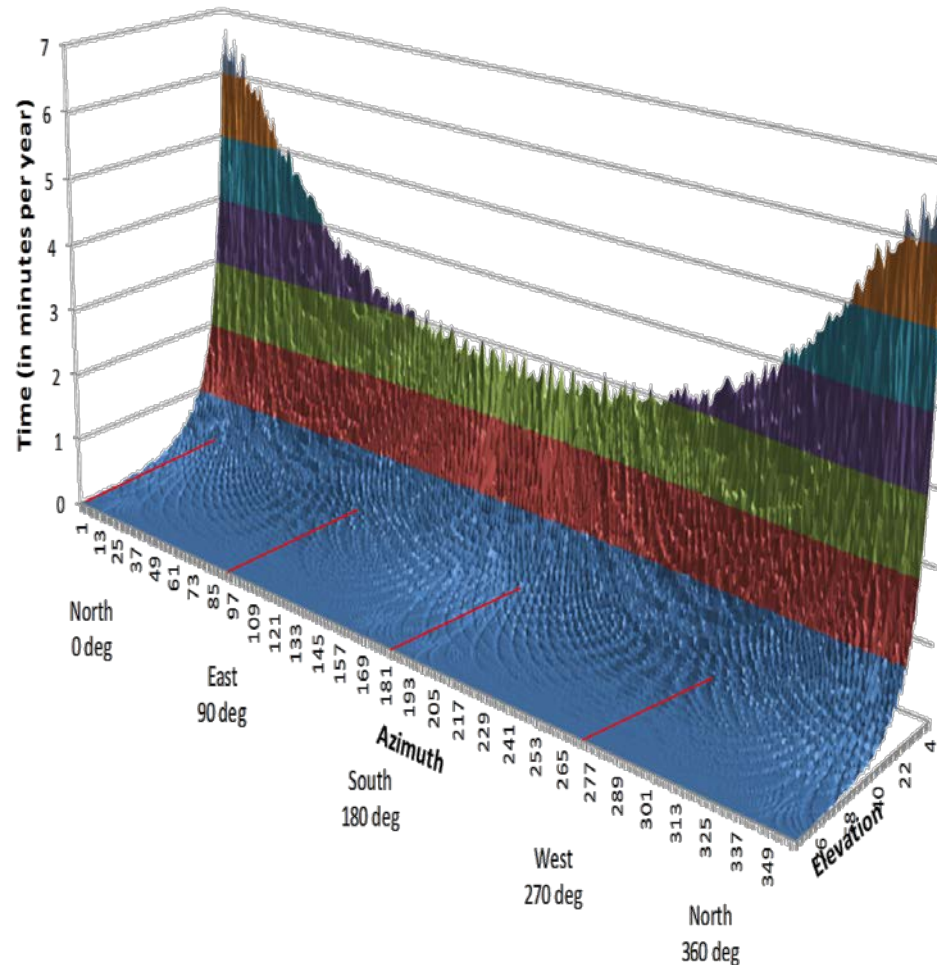
Impacts Of Model Uncertainties

- Effects of propagation loss uncertainties upon Power and Threshold Exceedance Plots
 - *Due to change in propagation path electrical parameters (soil conductivity and dielectric constant and surface refraction)*
 - *Due to regional characteristics (climate types and terrain types)*
 - *Due to variations in time (diurnal and seasonal)*
 - *Due to MW station receiver siting (constrained to achieve exposure to handsets while minimizing exposure to interference)*
 - *Due to limited terrain database resolution*
- Effects of SATOPS modeling enhancements upon power and Threshold Exceedance Plots
 - *Due to antenna pattern approximation (due to use of envelope mask)*
 - *Due to variation in radiate start/stop times*
 - *Due to use of elevation angle to first obstacle*

Methodology

Visibility Time as a Function of Ground Antenna Pointing Angles

- The figure represents an example visibility for a single non-geostationary satellite with one frequency uplink accumulated over one year in $1^\circ \times 1^\circ$ Az/EI cells
- Calculations include the number of minutes per year that a given antenna points in a given azimuth and elevation in supporting one single non-geostationary satellite
- Illustrative of the type of data that is combined for multiple satellites in arriving at a composite profile for the earth station's radiation over the year
- Note the antenna only points in any given direction a small percentage of the time



Methodology

Power Contour Plots

- Computational details are presented in Appendix B
- These calculations use 1 kW transmitter power for AFSCN sites for the analysis
 - *The AFSCN power actually varies from 500 W to ~ 7 kW, within the US*
 - *A few maximum power cases are included for comparison **
- The contours are calculated using the NTIA Irregular Terrain Model (ITM) with the GLOBE Terrain Data Base for propagation loss and are accurate to 1 and 5 km grid spacing as labeled
 - *1 or 5 km grid spacing, as limited by the GLOBE data base, adds considerable uncertainty because natural terrain features can be greatly varied over these distances*
- This model does not take into account vegetation or artificial structures so a 20 dB attenuation factor on the radiated signal was also added to some of the analyses cases

Methodology

Mobile Wireless Long Term Evolution (LTE) System Threshold Exceedance

- The received power level was calculated and compared to the LTE threshold of -137.4 dBW (1dB desense level) for each potential LTE base station site and at each antenna pointing angle
 - *The percentage non-exceedance time is that which the MW base stations can operate without RFI given the stated LTE threshold*
 - *1 dB desense level is used as the interference criterion for the LTE receiver; it is the level at which the apparent receiver noise floor is increased by 1 dB, thereby reducing the effective sensitivity by 1 dB*
- The center color of the plot(s) (i.e. nearest to the ground station) represents the minimum value of threshold non-exceedance which is the complement of the site radiation percentage time
- This study uses aggregated statistics of radiation to spacecraft over a given band for the past year

Study Results

- Using data characterizing typical SATOPs at the selected sites, and applying propagation modeling as described, contour plots in Appendix A were generated
 - *Power Contour Plots in the relative vicinity of the sites as a function of azimuth and distance*
 - *Threshold Exceedance Plots of the probability that the predicted SATOPS signal level at various points of azimuth and distance does not exceed the threshold interference criterion*
- Results are subject to uncertainties of the modeling process further elaborated in Appendix B.

Summary

- SATOPS information requested by the CSMAC WG 3 to assess Government and commercial sharing of the 1755-1850 MHz band is provided
- A methodology for estimating power contours over geographic areas is presented
- Limitations of using various models to simulate power profiles are described
- Results are based on general usage but are not actual operational scenarios for Government SATOPS ground sites
- This study is not intended to support any derivation of requirements
- Impacts to future commercial operations can only be estimated at this time
- Still need to assess actual ground site parameters for potential impacts
- Regulatory provisions should allow for potential changes in Government mission requirements including the possibility of greater satellite contact times, higher power levels at existing sites and the addition of new sites

Study References

1. Satellite Orbit Analysis Program (SOAP), The Aerospace Corporation, OTR20130314155423, 2013
2. “Integrated Terrain Model” by NTIA/ITS, see:
<http://www.its.blrdoc.gov/resources/radio-propagation-software/itm/itm.aspx>
3. The Global Land One-km Base Elevation Project (GLOBE) Elevation Database, National Geophysical Data Center, NOAA; available online at:
<http://www.ngdc.noaa.gov/mgg/topo/globe.html>
4. Commerce Spectrum Management Advisory Committee, Final Report, Working Group 1 – 1695-1710 MHz Meteorological-Satellite, dated 1/22/2013, downloaded from:
<http://www.ntia.doc.gov/other-publication/2013/csmac-wg-1-final-report-v2>
5. “Antenna Models for Electromagnetic Compatibility Analyses,” NTIA TM-13-489, National Telecommunication and Information Administration Technical Memorandum, October 2012
6. “Government Satellite Control Overview”, 2 Oct 12 [Government submittal 1 to CSMAC WG3]
7. NTIA Manual of Regulation and Procedures for Federal Radio Frequency Management, May 2012

Appendix A: Study Results

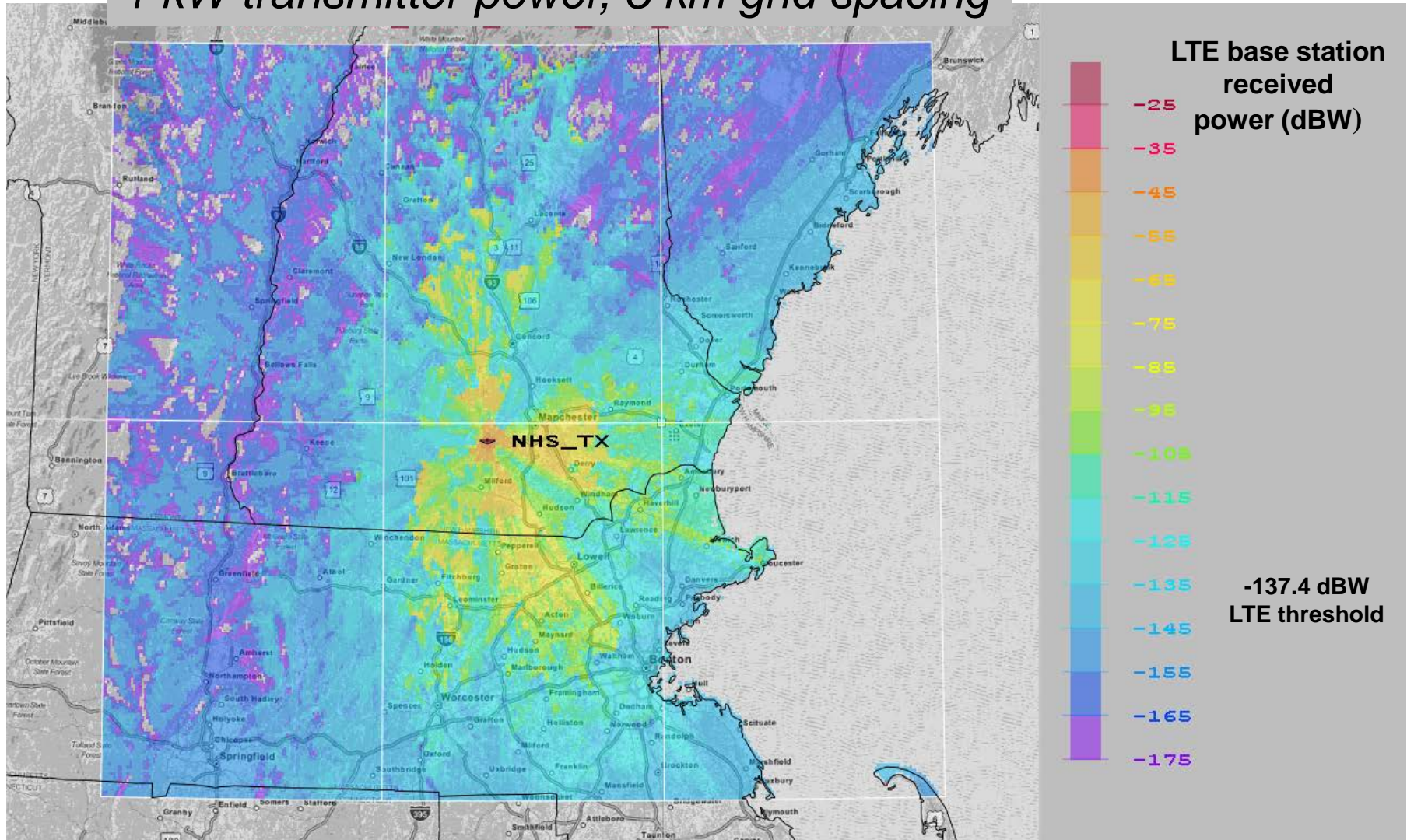
Appendix A – Index of Study Results

Type of Plot	Grid (km)	Site					
		NHS	VTS	HTS	BPTF	FB/AK	LP/CA
Power Contour	5	22-23	36-37	48-49, 51	59-60	67-68	70-71
Power Contour with 20 dB attenuation	5	24-25	38-39	50, 52	61-62	67-68	72-73
LTE Threshold Exceedance 1755-1780 MHz	5	26	42	53	63		
LTE Threshold Exceedance 1755-1780 MHz	1				65	69	
LTE Threshold Exceedance 1755-1780 MHz, with 20 dB attenuation	1	27	43	54	64,66	69	
LTE Threshold Exceedance 1780-1805 MHz	5	28	44	55			74
LTE Threshold Exceedance 1780-1805 MHz	1						75
LTE Threshold Exceedance 1780-1805 MHz, with 20 dB attenuation	1	29	45	56			
LTE Threshold Exceedance 1805-1850 MHz	5	30	46	57			
LTE Threshold Exceedance 1805-1850 MHz, with 20 dB attenuation	1	31	47	58			
Power Contour (radiating at 5.02 kW)	5		40				
Power Contour (radiating at 5.02 kW) with 20 dB attenuation	5		41				
Power Contour (radiating at 7.244 kW)	5	32					
Power Contour (radiating at 7.244 kW) with 20 dB attenuation	5	33					
LTE Threshold Exceedance 1755-1780 MHz (radiating at 7.244 kW)	5	34					
LTE Threshold Exceedance 1755-1780 MHz (with 10 dB standard deviation applied to propagation loss)	5	35					

* Unless otherwise stated in the Table, charts reflect transmit power of 1 kW except BPTF power of 300 W.

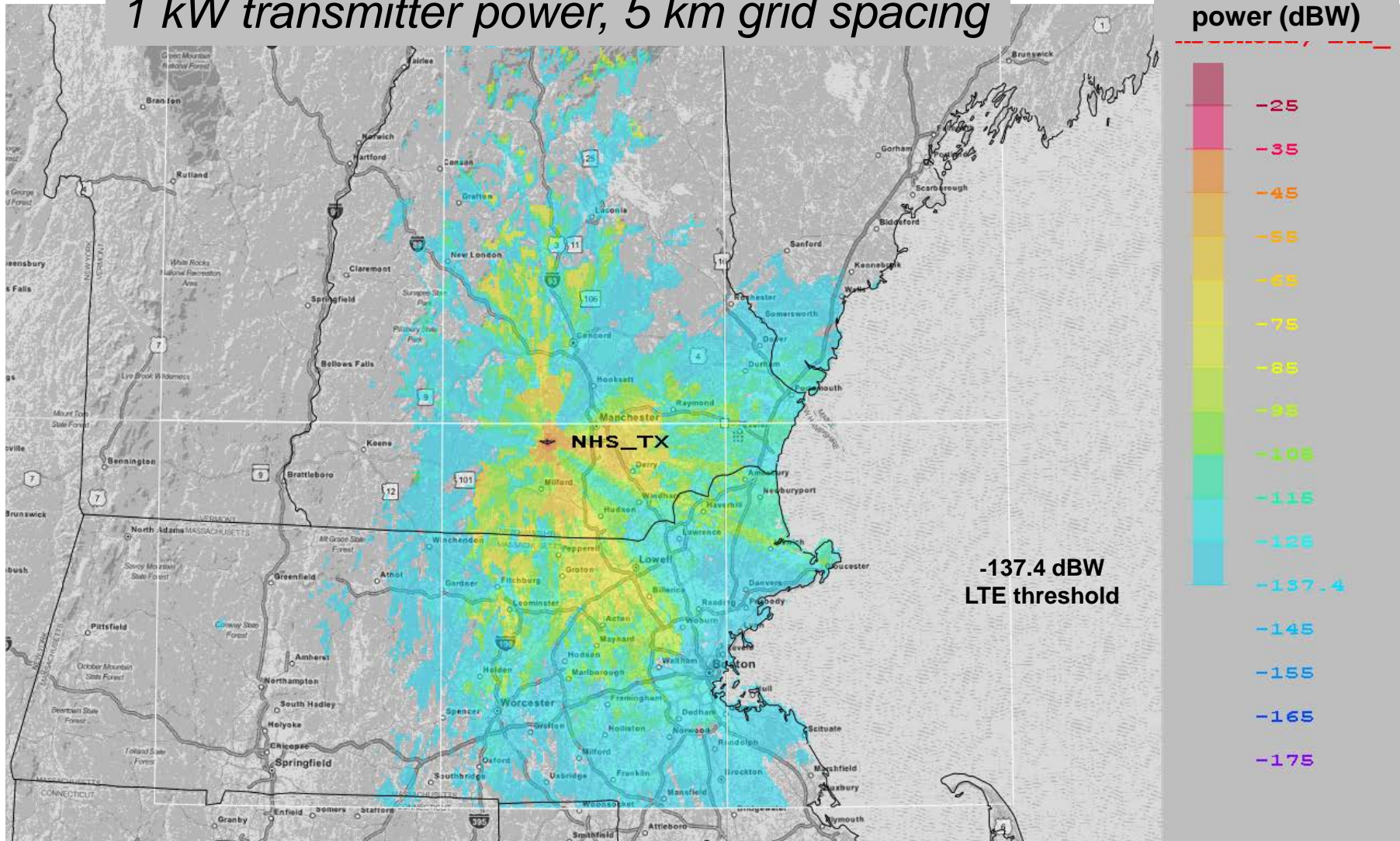
NHS Power Contours

1 kW transmitter power, 5 km grid spacing



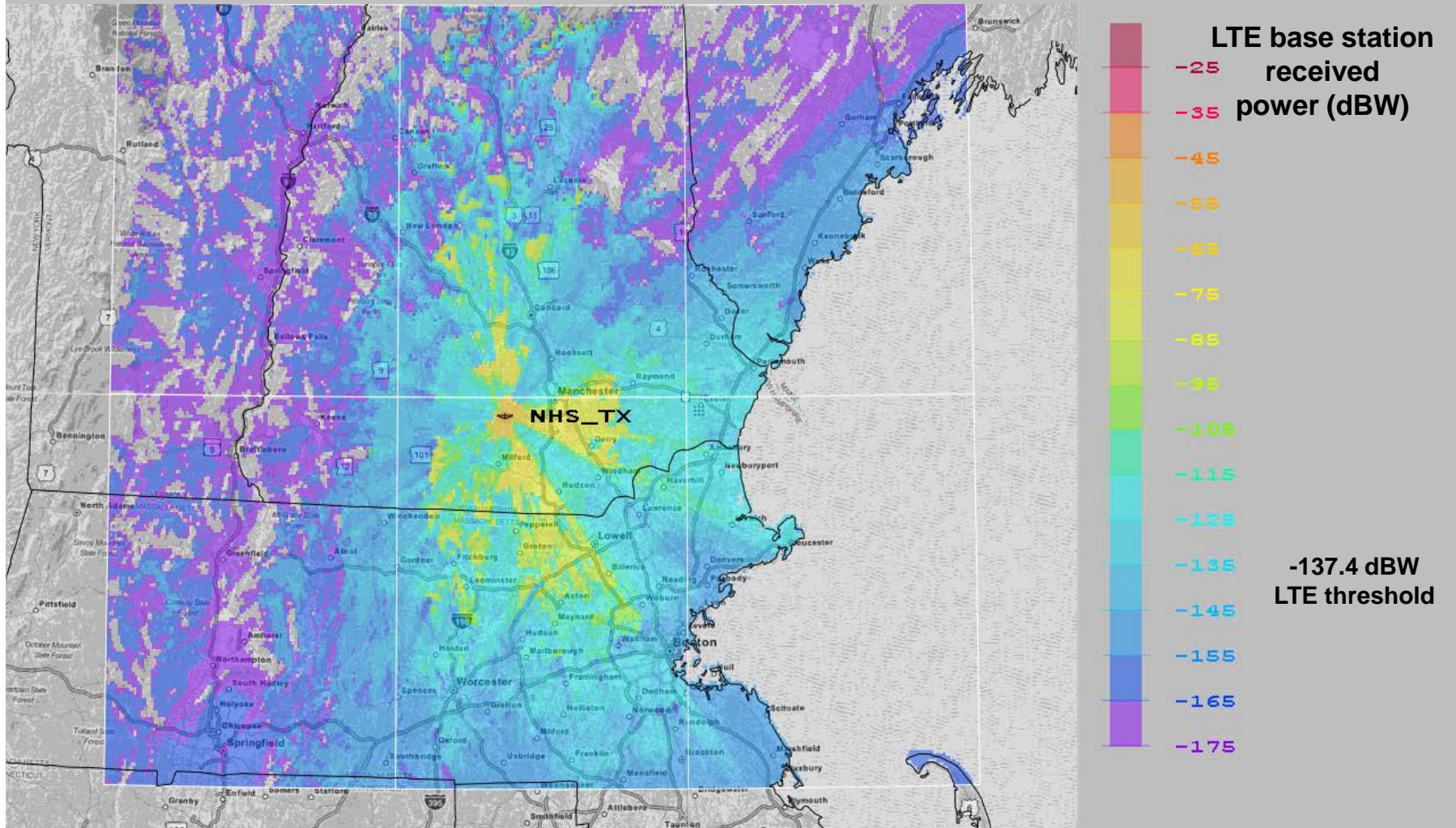
NHS Radiated Power With Natural Terrain in Gray Indicating Power Below Threshold

1 kW transmitter power, 5 km grid spacing



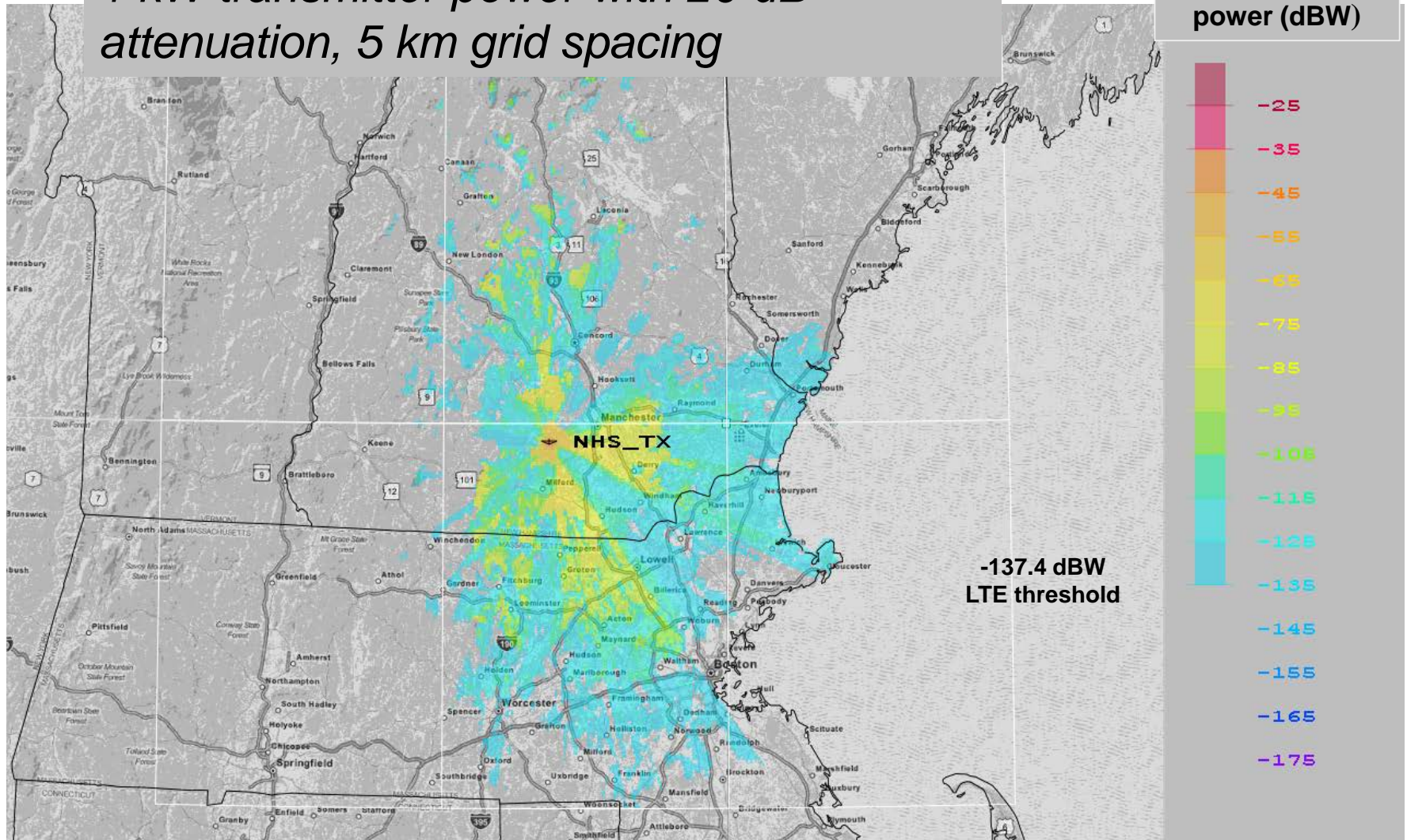
NHS Power Contours

1 kW transmitter power, 20 dB attenuation, 5 km grid spacing



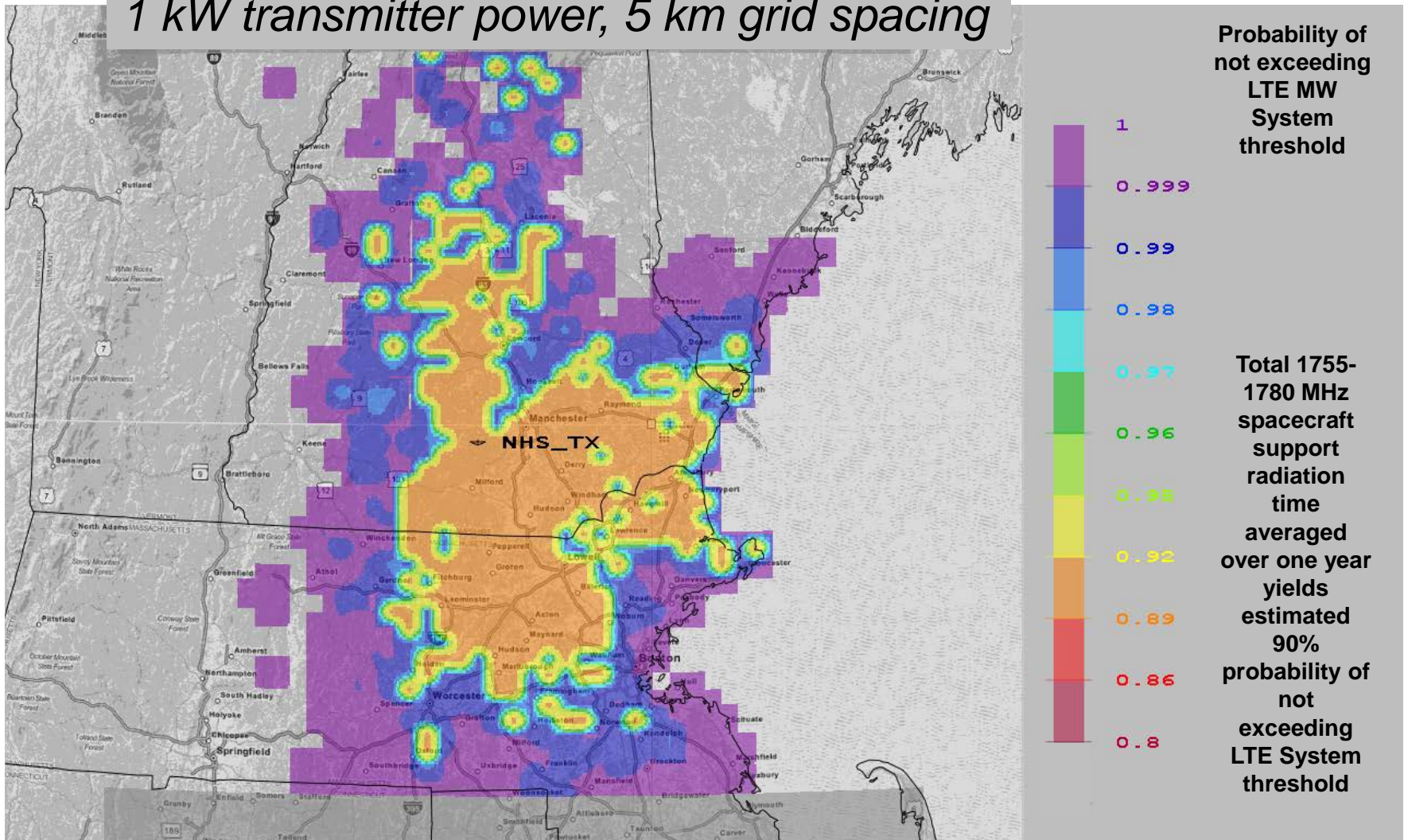
NHS Radiated Power With Natural Terrain in Gray Indicating Power Below Threshold

*1 kW transmitter power with 20 dB
attenuation, 5 km grid spacing*



NHS LTE System Threshold Exceedance, 1755-1780 MHz

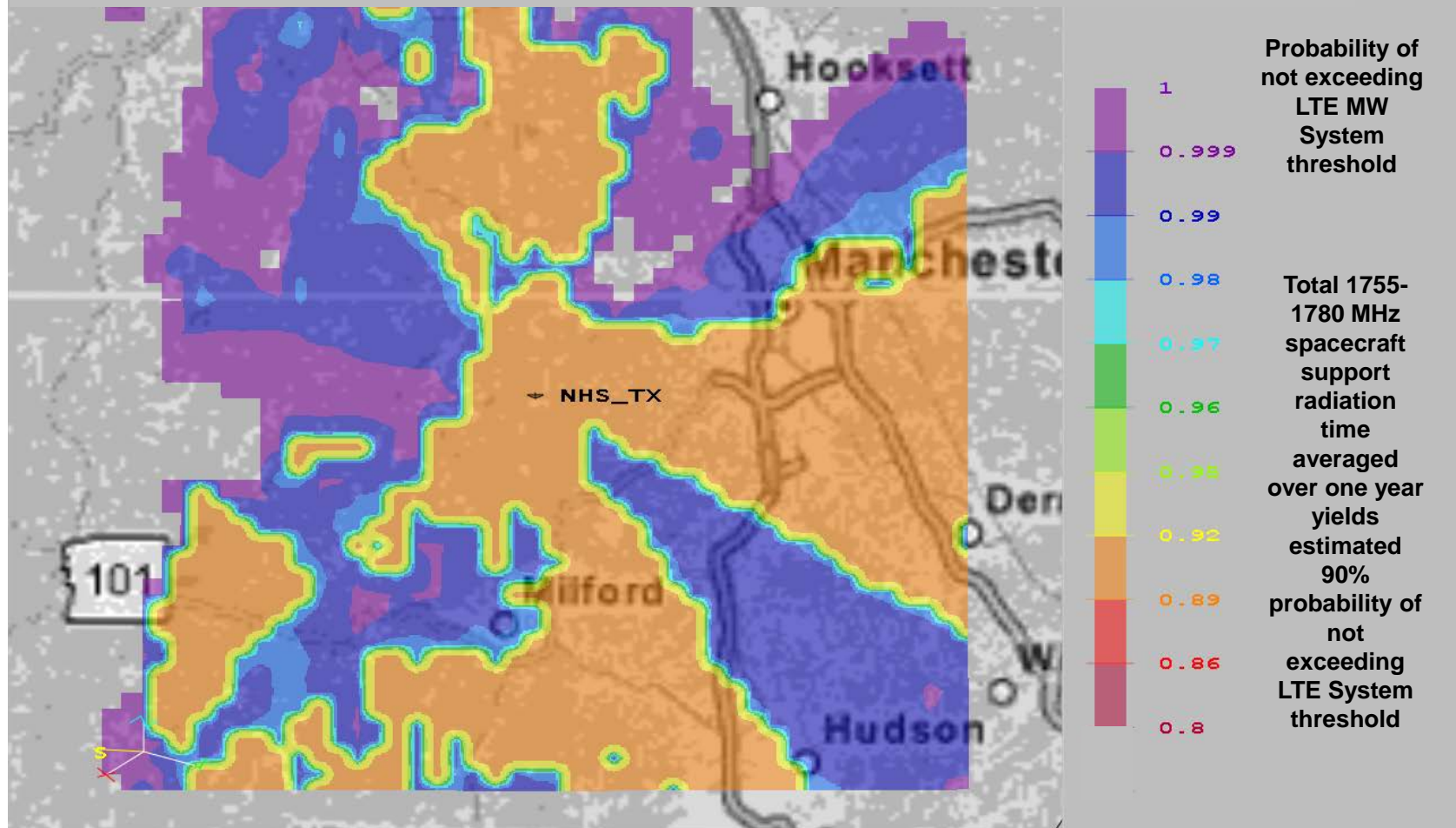
1 kW transmitter power, 5 km grid spacing



NHS LTE System Threshold Exceedance, 1755-1780 MHz

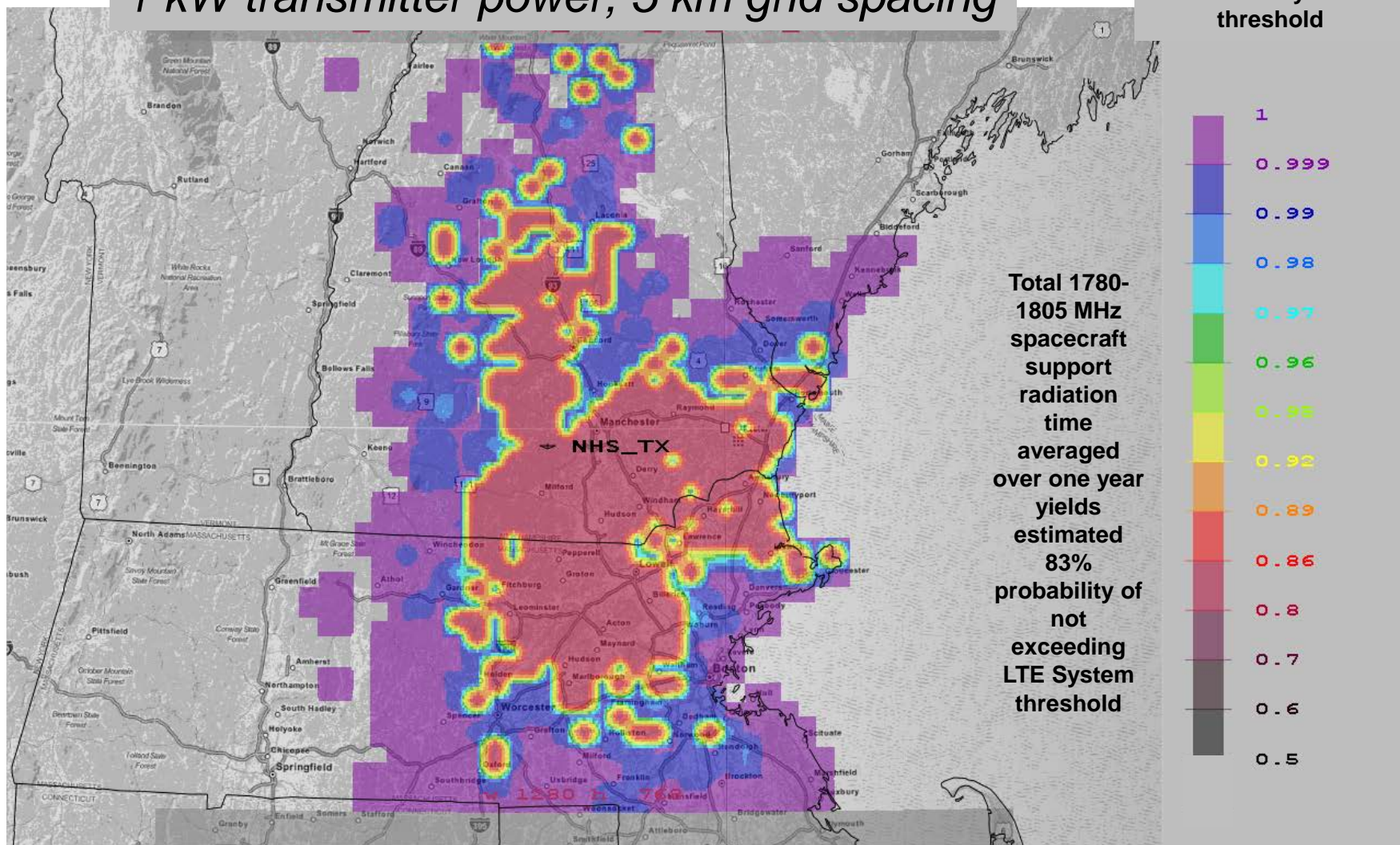
Plots of this type are magnified by a factor of five compared with the previous plots

1 kW transmitter power, 20 dB attenuation, 1 km grid spacing



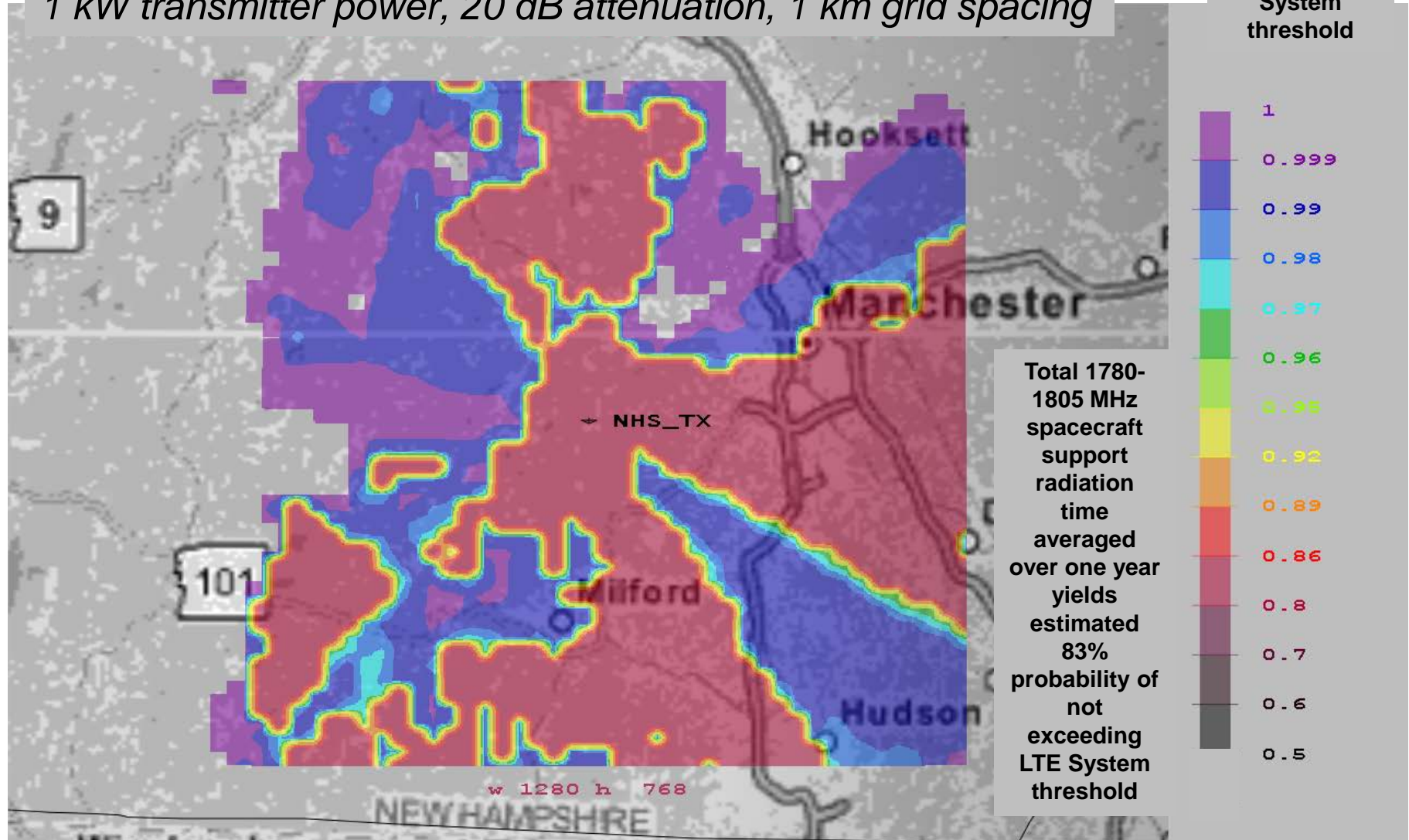
NHS LTE System Threshold Exceedance, 1780-1805 MHz

1 kW transmitter power, 5 km grid spacing



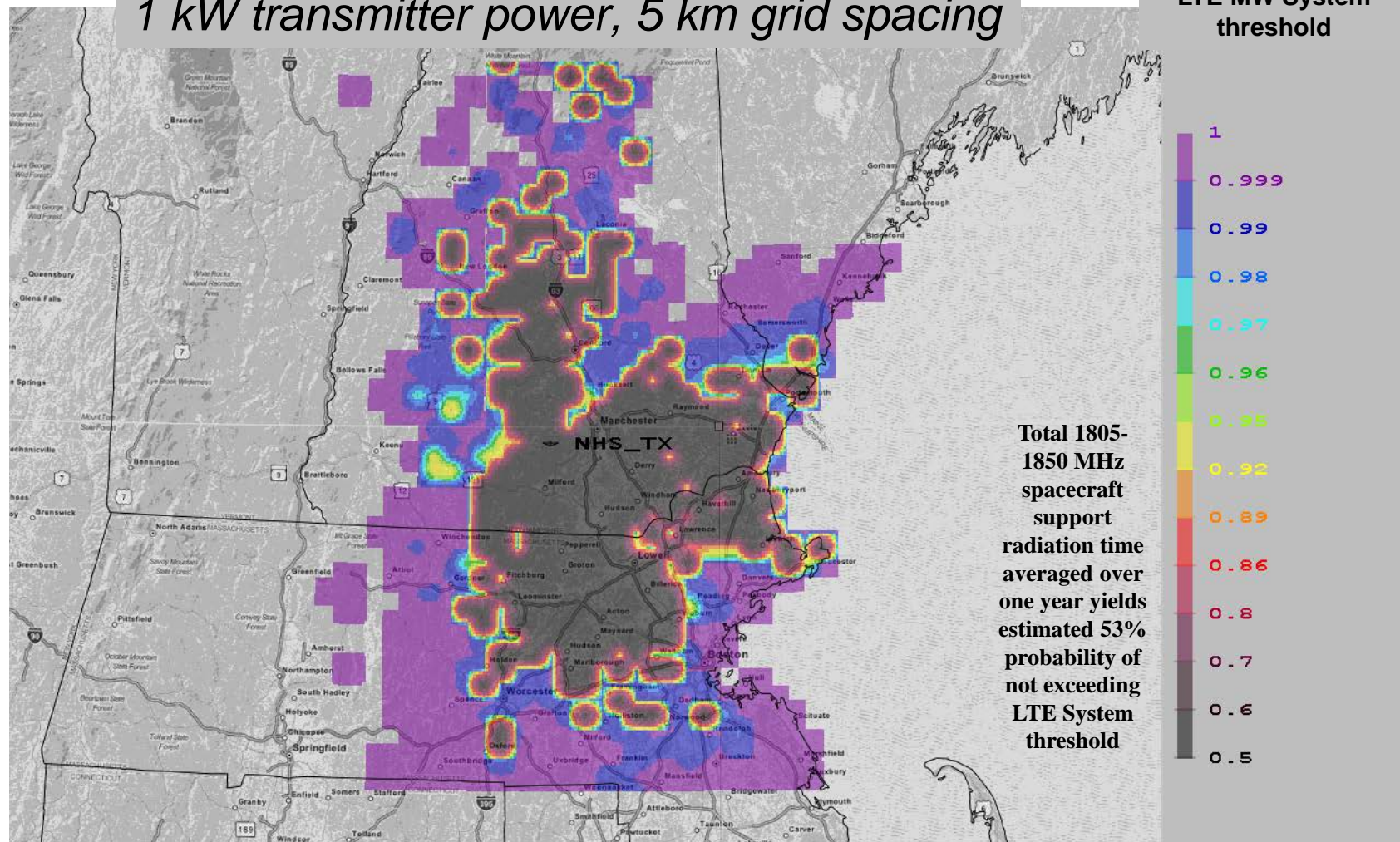
NHS LTE System Threshold Exceedance, 1780-1805 MHz

1 kW transmitter power, 20 dB attenuation, 1 km grid spacing



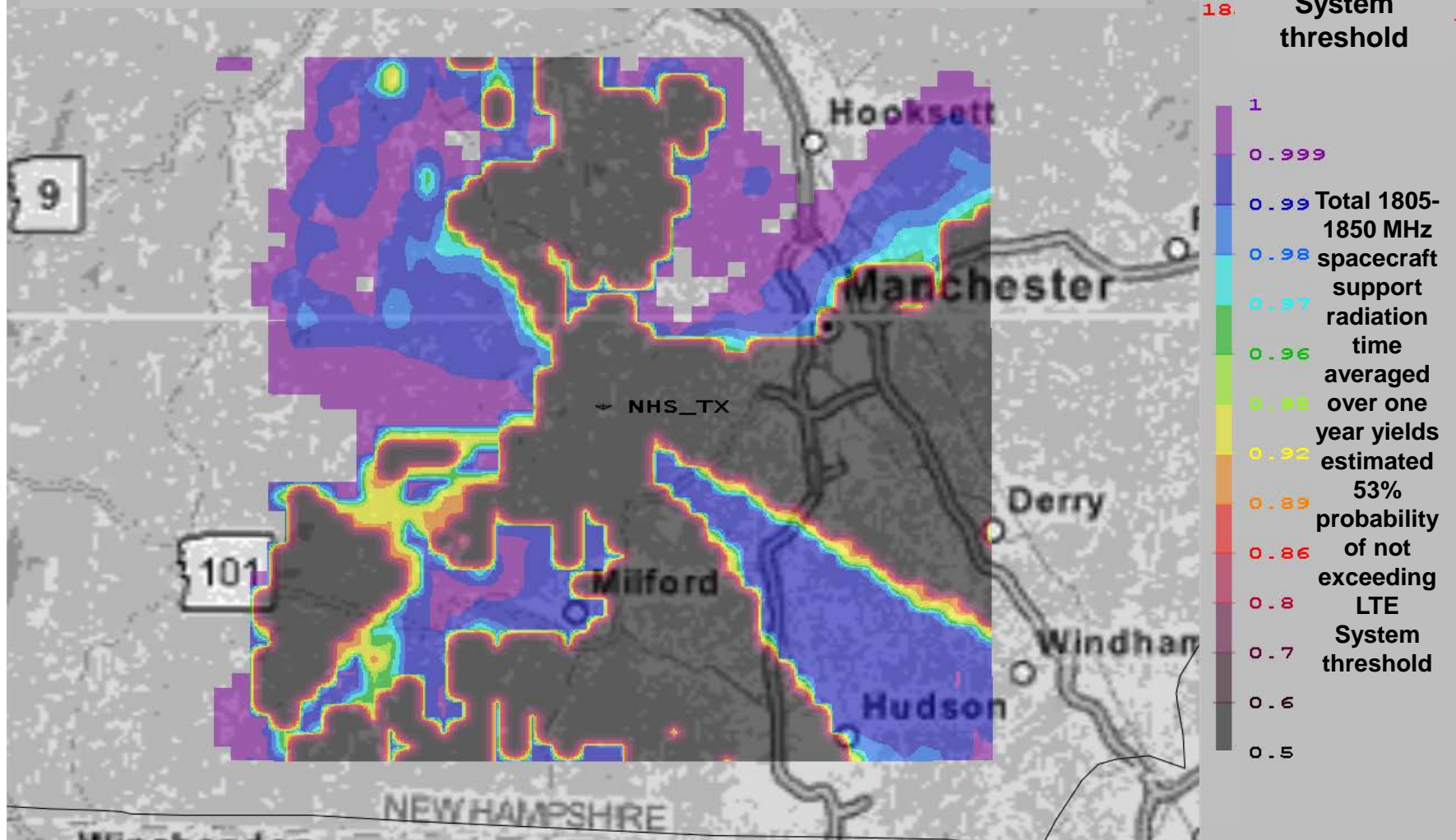
NHS LTE System Threshold Exceedance, 1805-1850 MHz

1 kW transmitter power, 5 km grid spacing



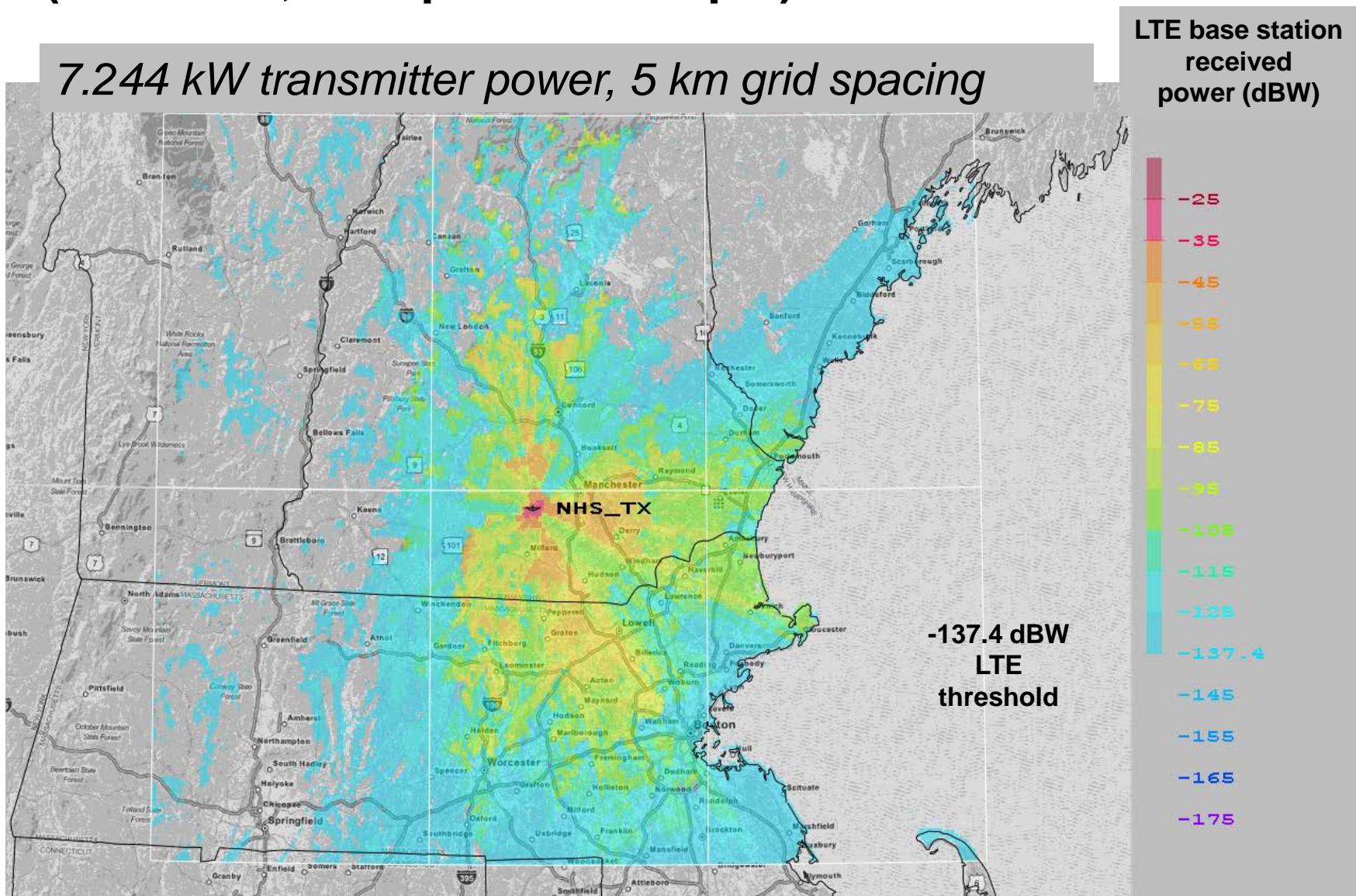
NHS LTE System Threshold Exceedance, 1805-1850 MHz

1 kW transmitter power, 20 dB attenuation, 1 km grid spacing



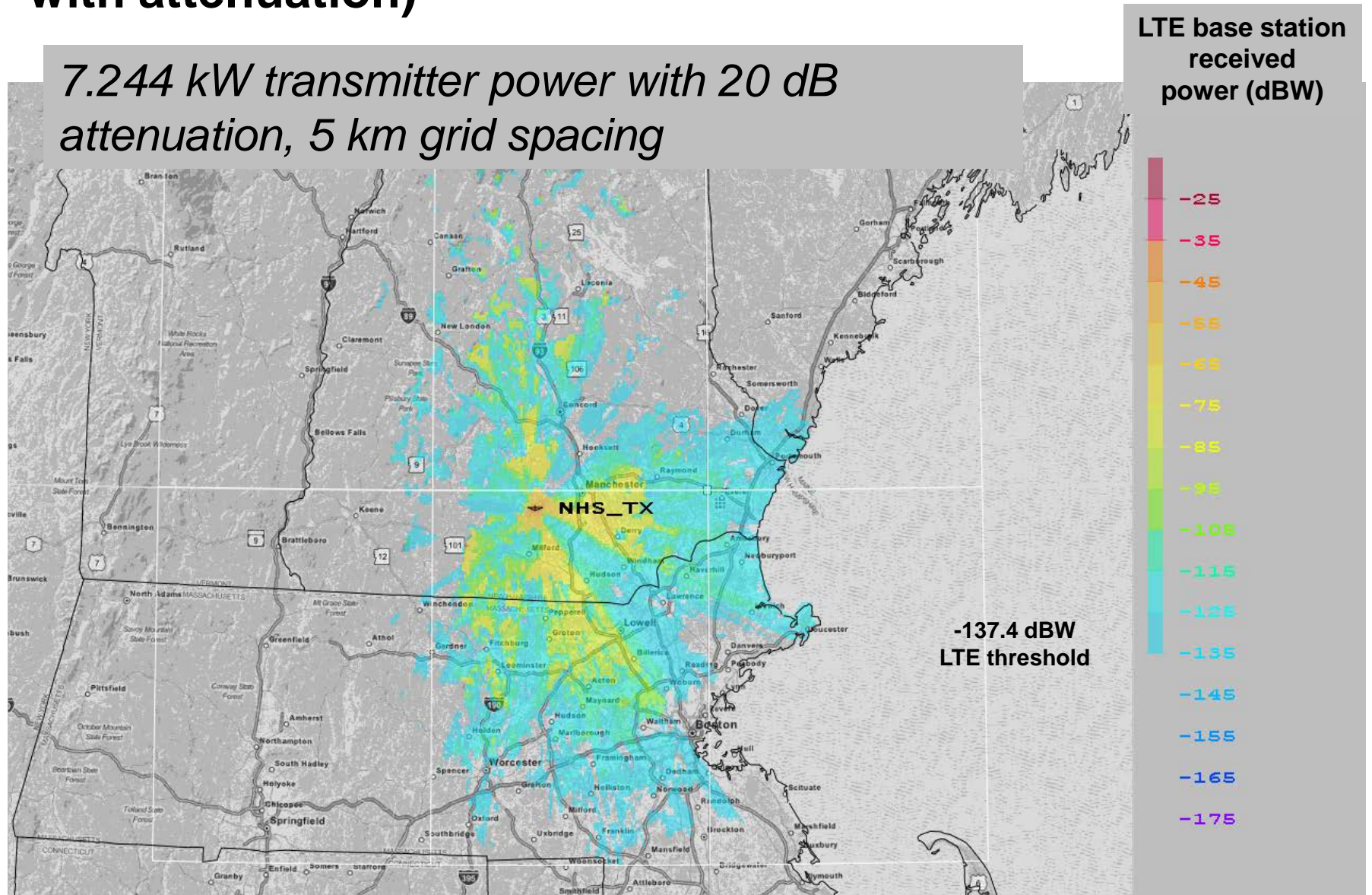
NHS Radiated Power (38.6 dBW, max power example)

7.244 kW transmitter power, 5 km grid spacing



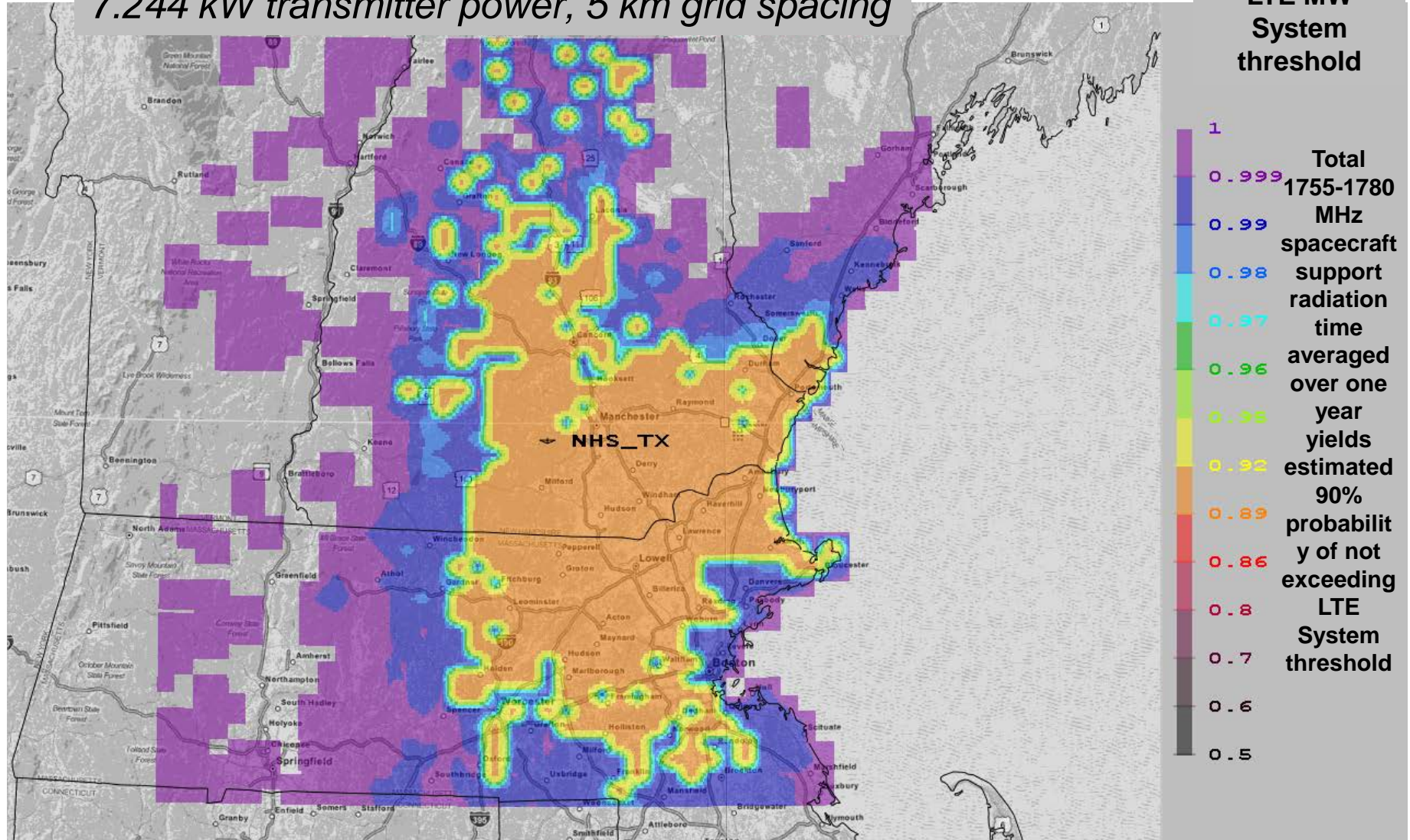
NHS Radiated Power (18.6 dBW, max power example with attenuation)

7.244 kW transmitter power with 20 dB attenuation, 5 km grid spacing



NHS LTE System Threshold Exceedance, 1755-1780 MHz (38.6 dBW, max power example)

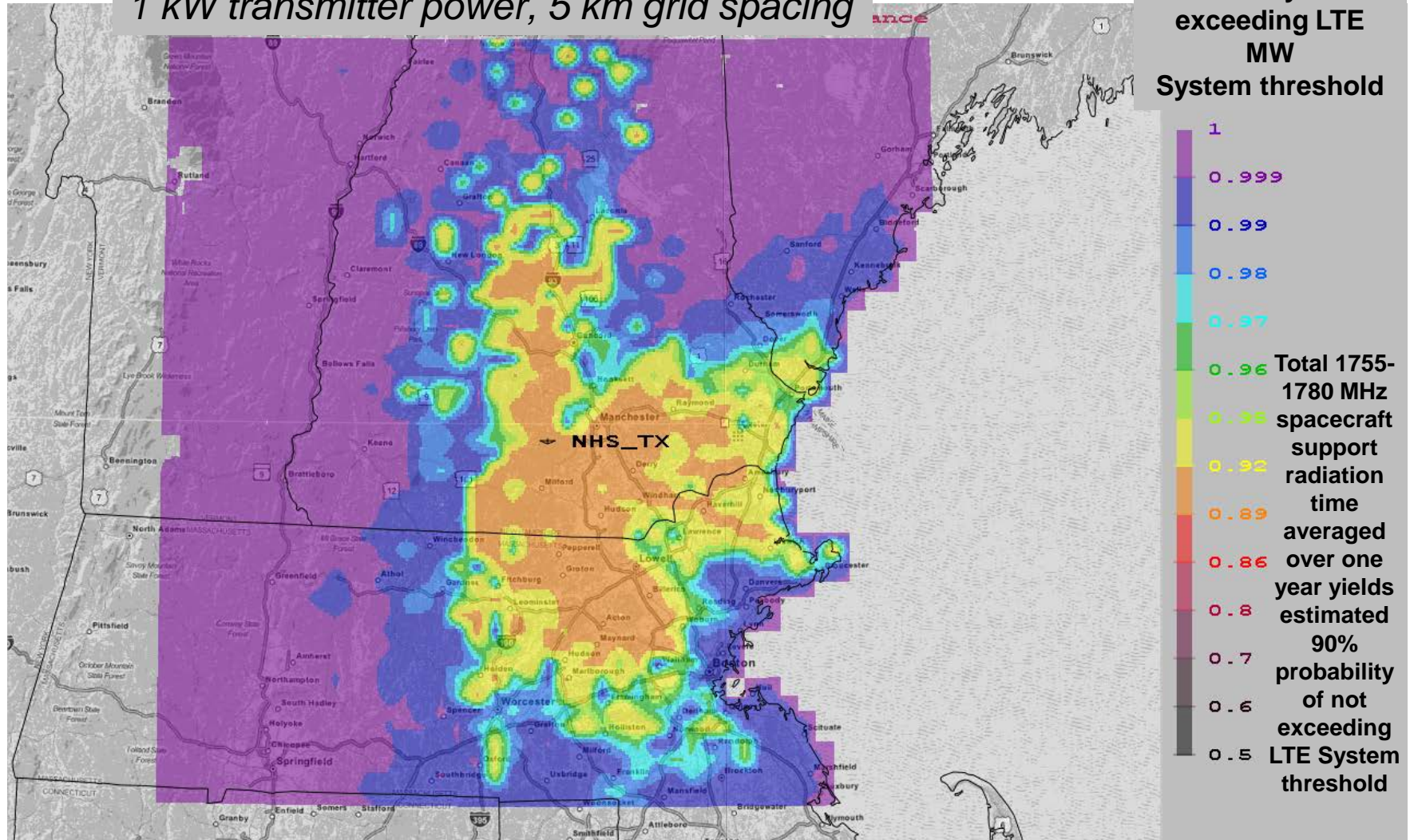
7.244 kW transmitter power, 5 km grid spacing



NHS LTE System Threshold Exceedance, 1755-1780 MHz

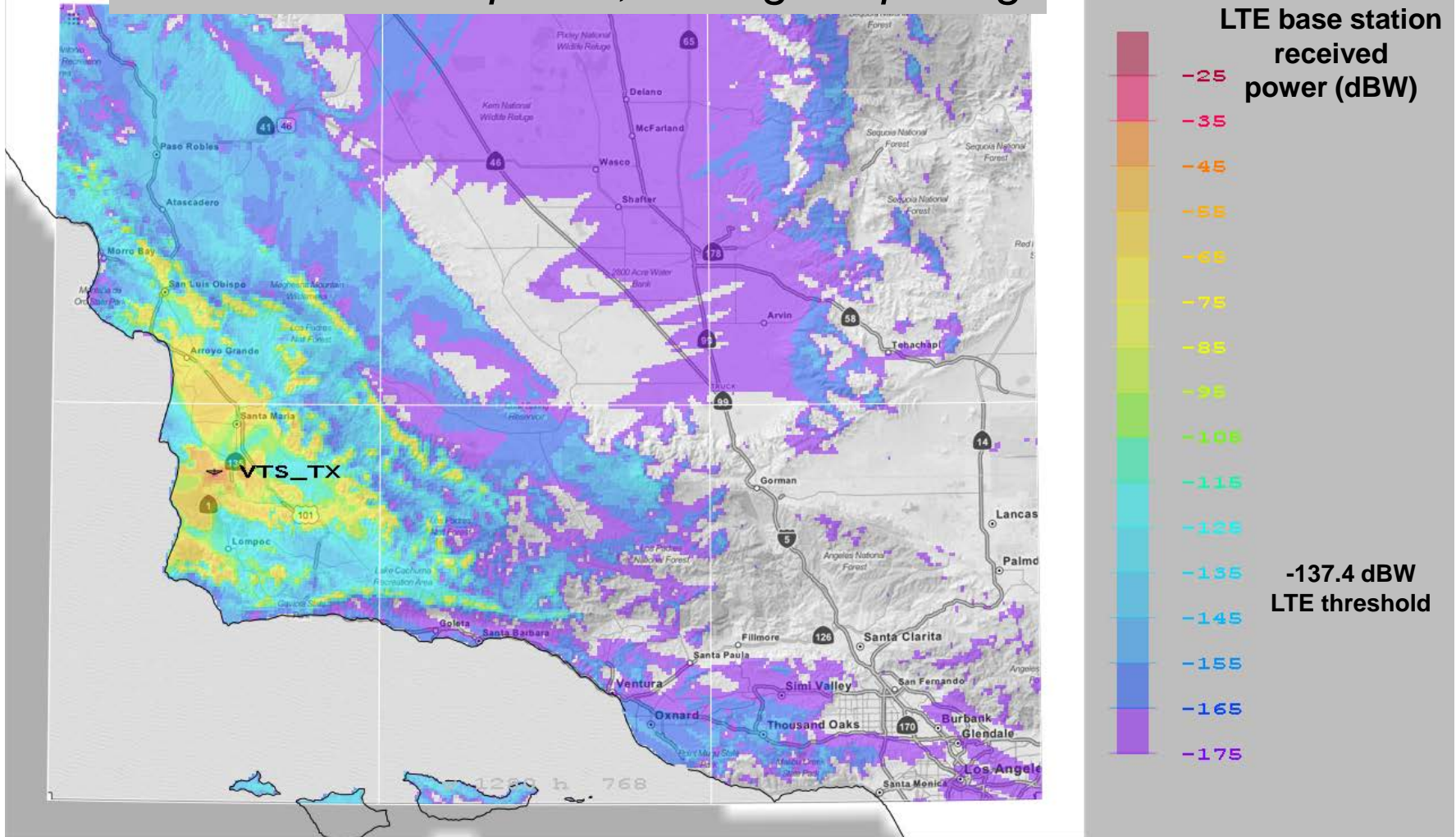
(Gaussian distribution applied with 10 dB standard deviation to receive power levels)

1 kW transmitter power, 5 km grid spacing



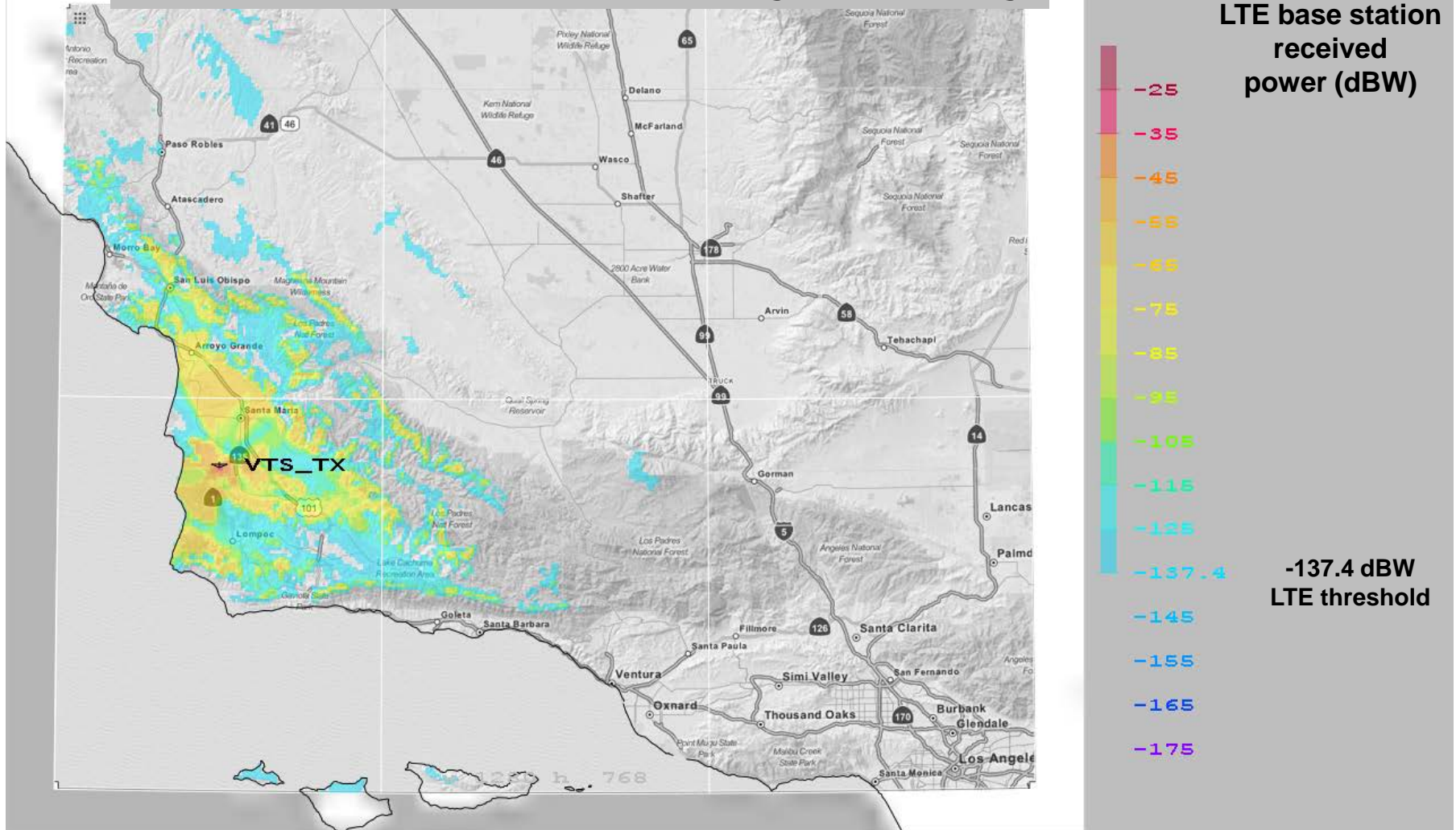
VTS Power Contours

1 kW transmitter power, 5 km grid spacing



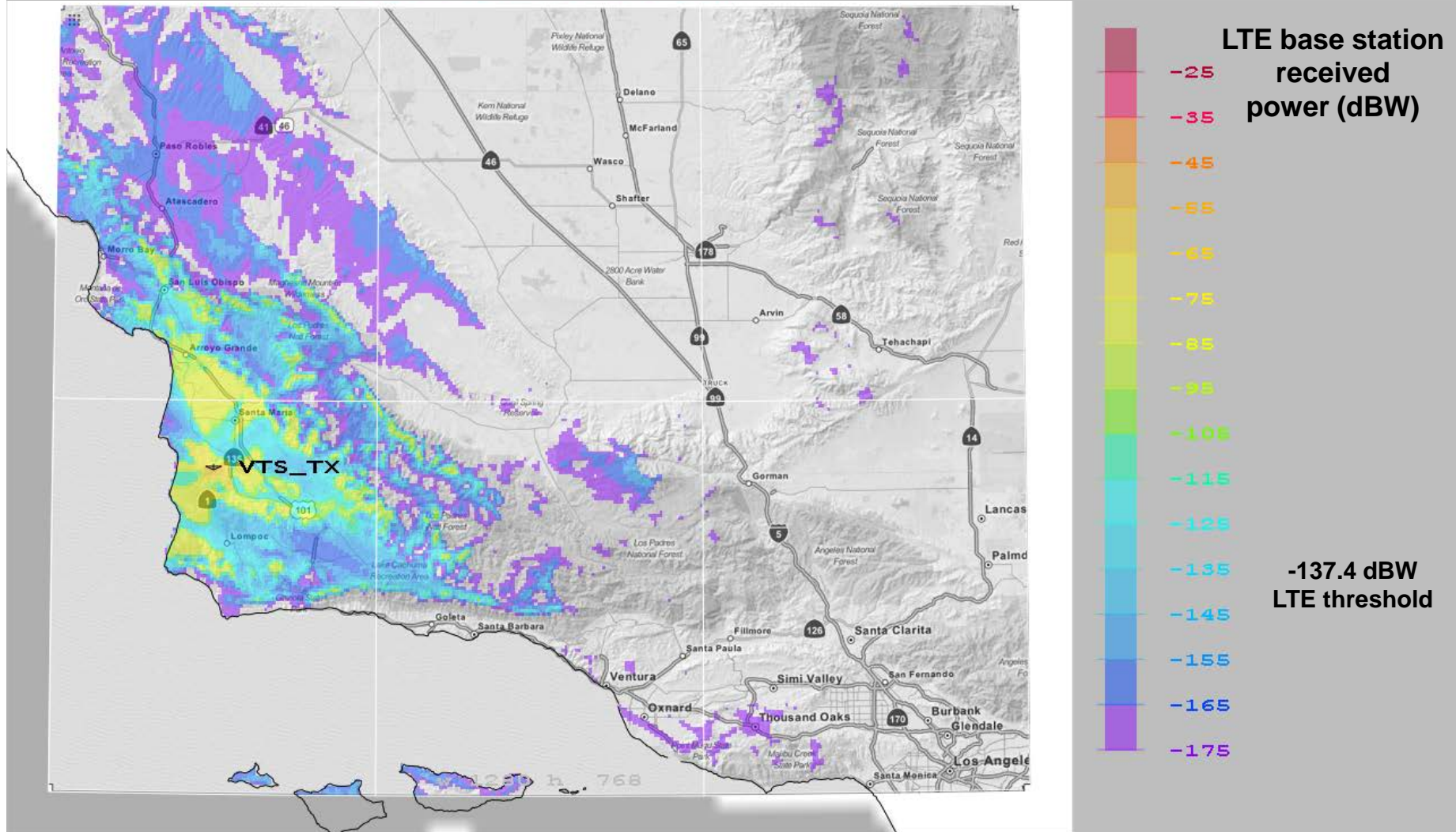
VTS Radiated Power With Natural Terrain in Gray Indicating Power Below Threshold

1 kW transmitter power, 5 km grid spacing



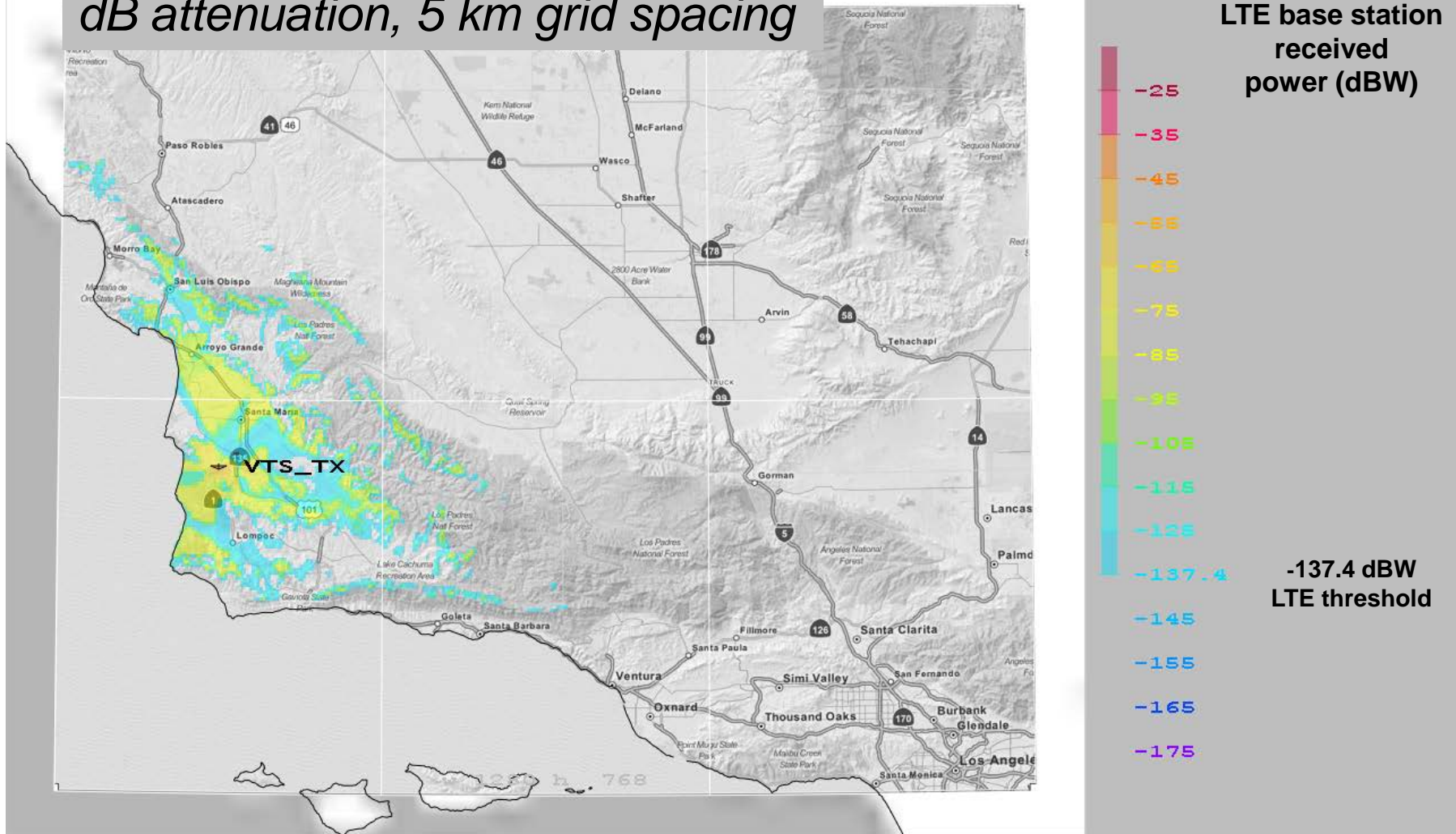
VTS Power Contours

1 kW transmitter power, with 20 dB attenuation, 5 km grid spacing



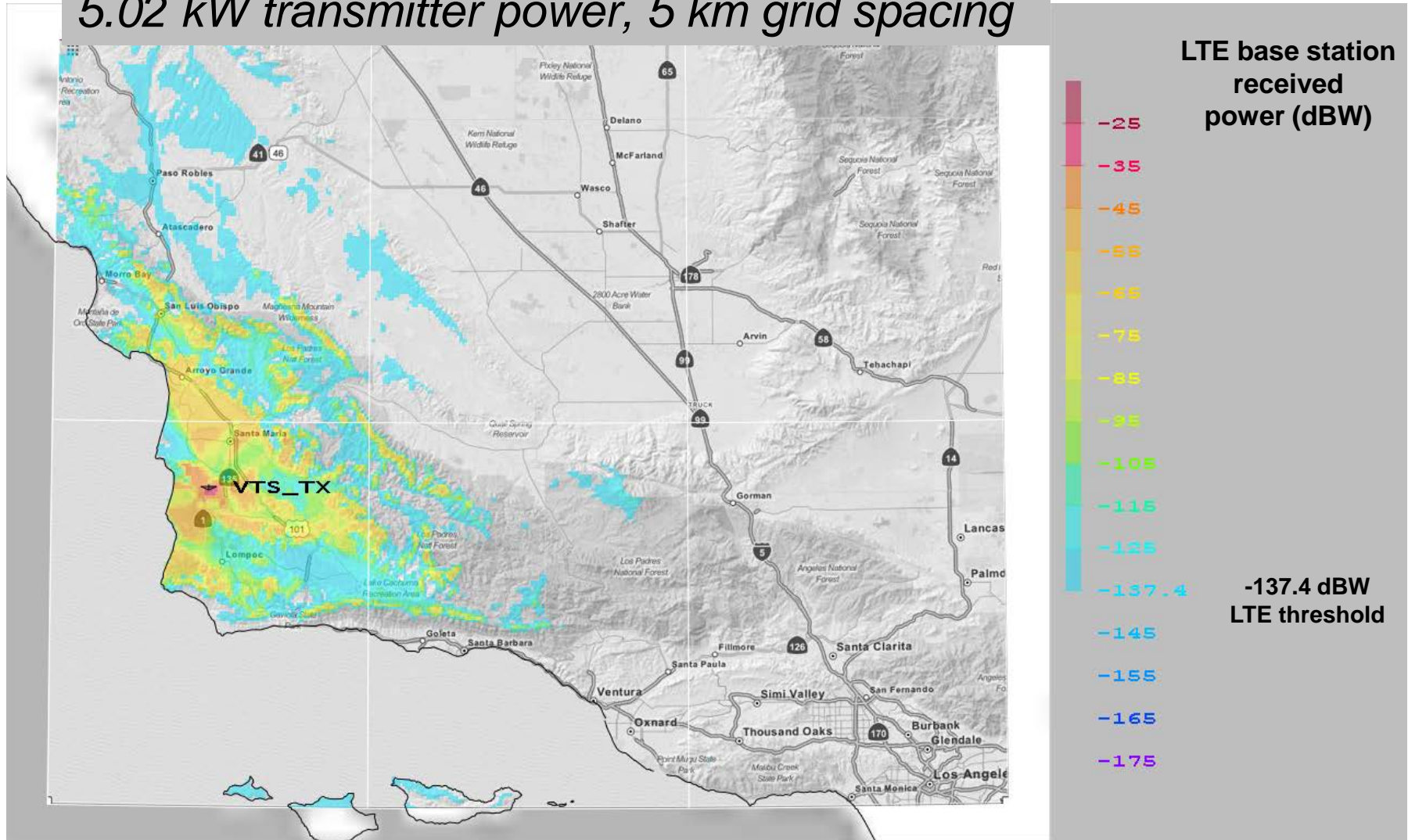
VTS Radiated Power With Natural Terrain in Gray Indicating Power Below Threshold

*1 kW transmitter power, with 20
dB attenuation, 5 km grid spacing*



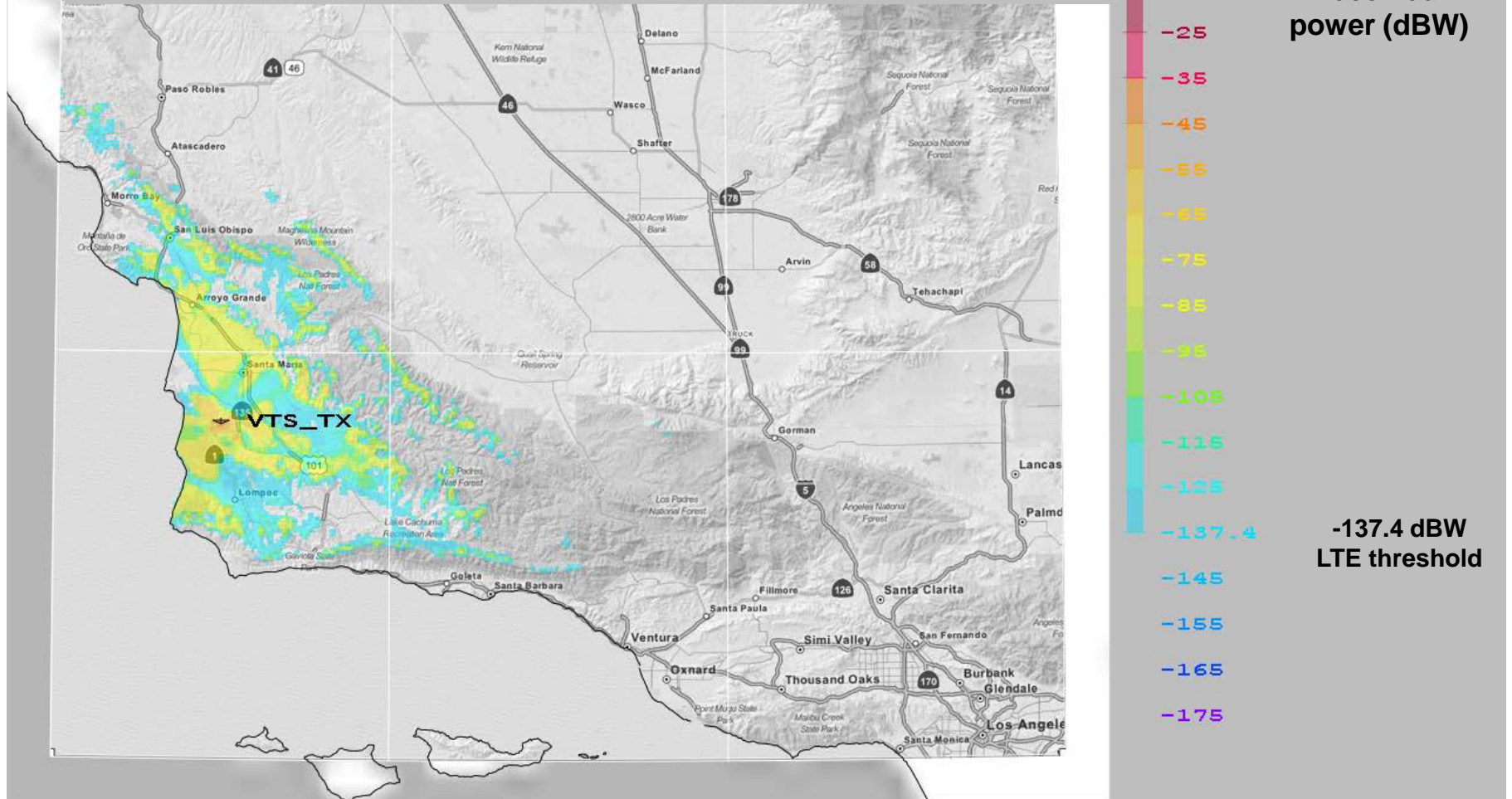
VTS Radiated Power (37.05 dBW, max power example)

5.02 kW transmitter power, 5 km grid spacing



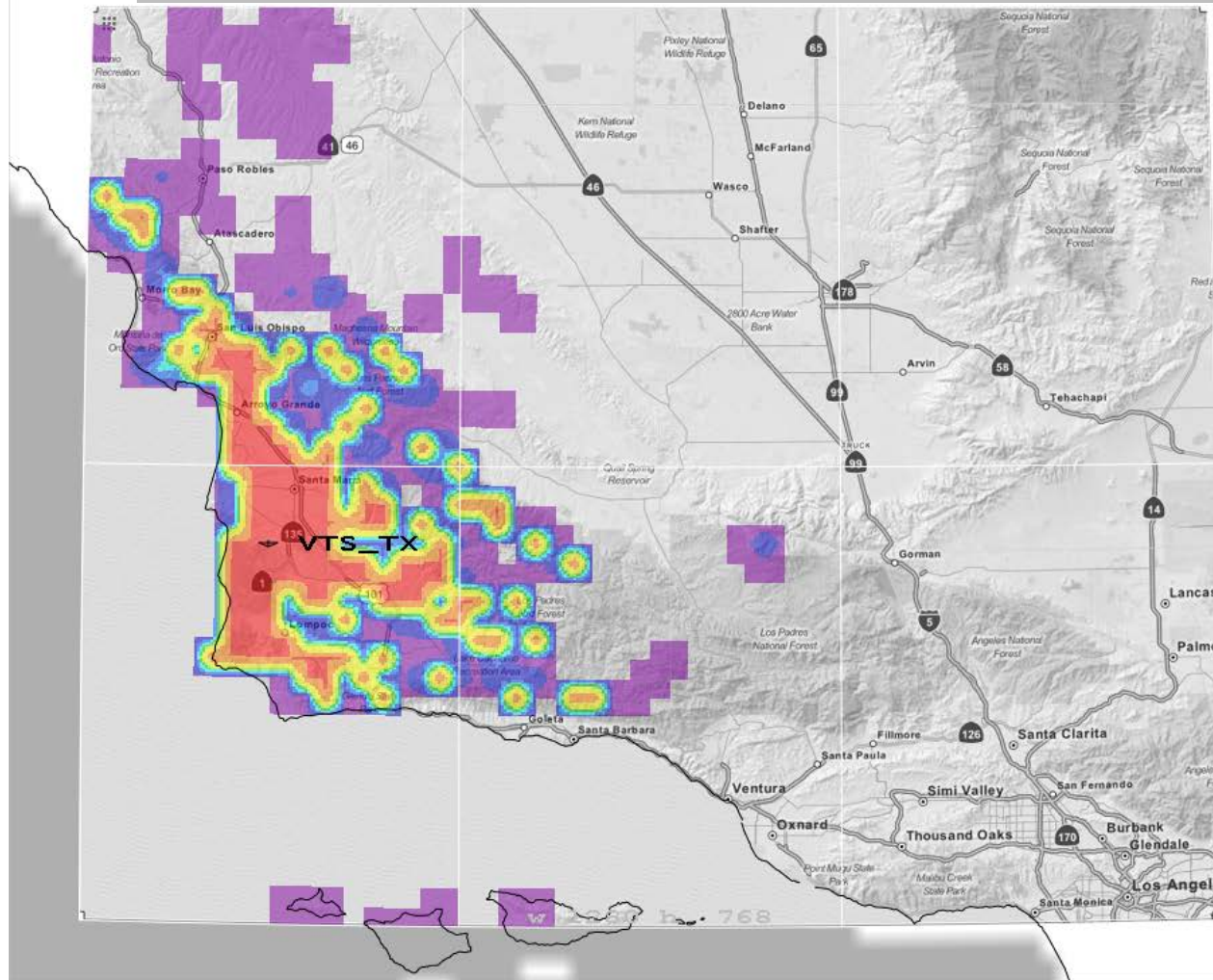
VTS Radiated Power (17.05 dBW, max power with attenuation)

*5.02 kW transmitter power, 20 dB attenuation,
5 km grid spacing*



VTS LTE System Threshold Exceedance, 1755-1780 MHz

1 kW transmitter power, 5 km grid spacing

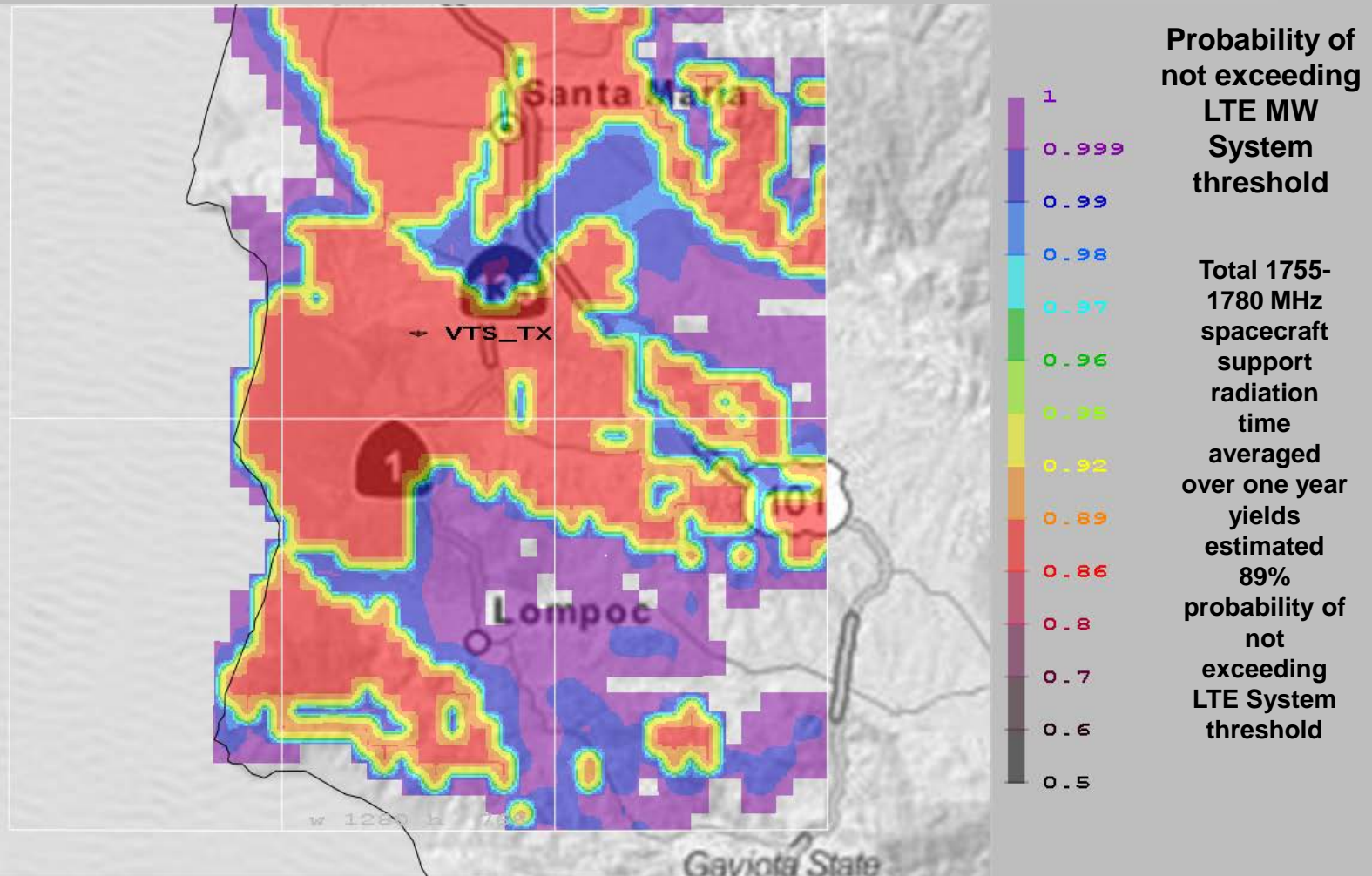


Probability of
not exceeding
LTE MW
System
threshold

Total 1755-
1780 MHz
spacecraft
support
radiation
time
averaged
over one year
yields
estimated
89%
probability of
not
exceeding
LTE System
threshold

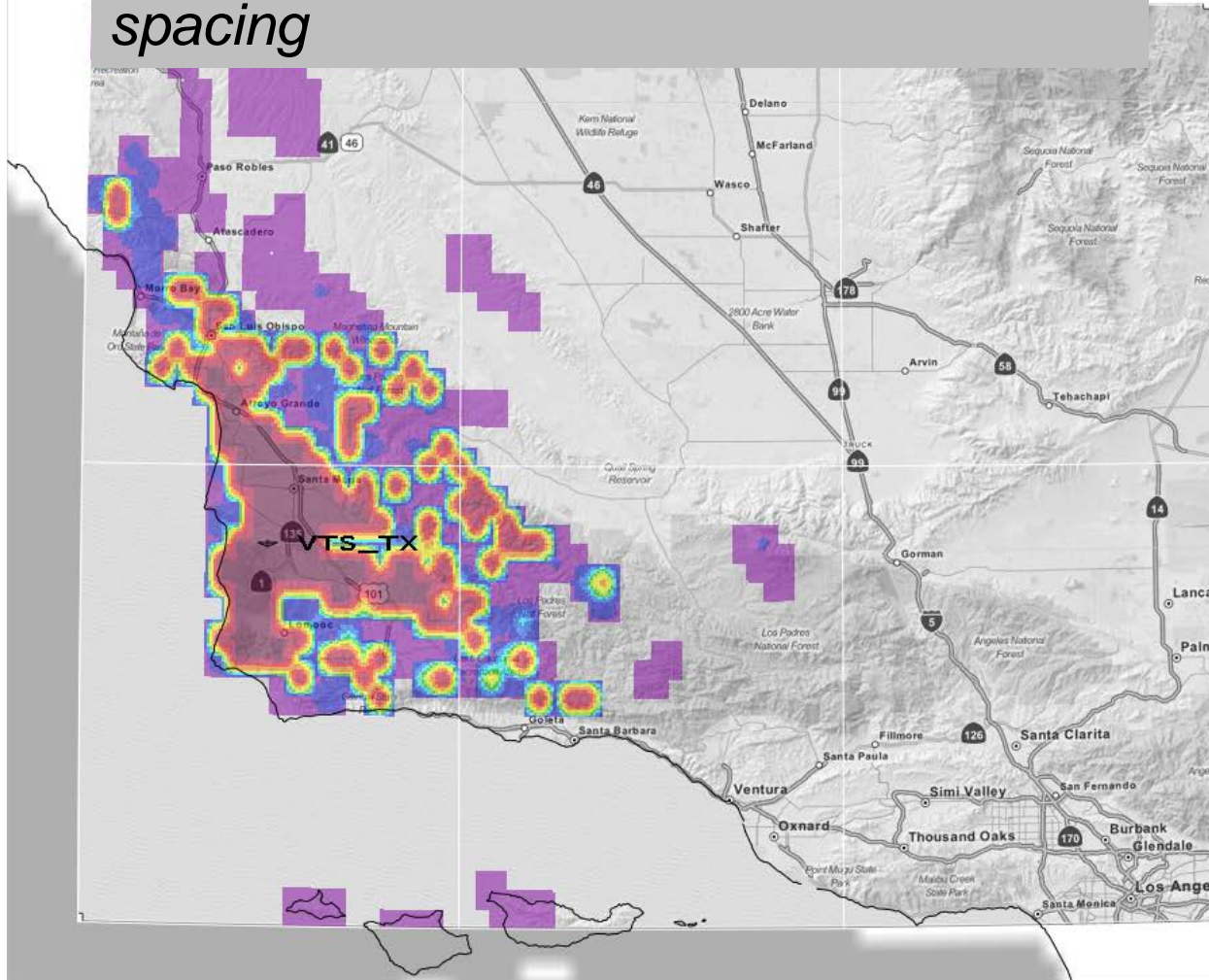
VTs LTE System Threshold Exceedance, 1755-1780 MHz

1 kW transmitter power, 20 dB attenuation, 1 km grid spacing

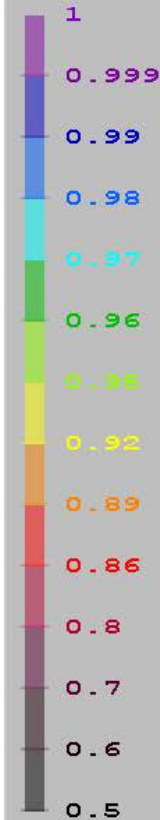


VTs LTE System Threshold Exceedance, 1780-1805 MHz

*1 kW transmitter power, 5 km grid
spacing*



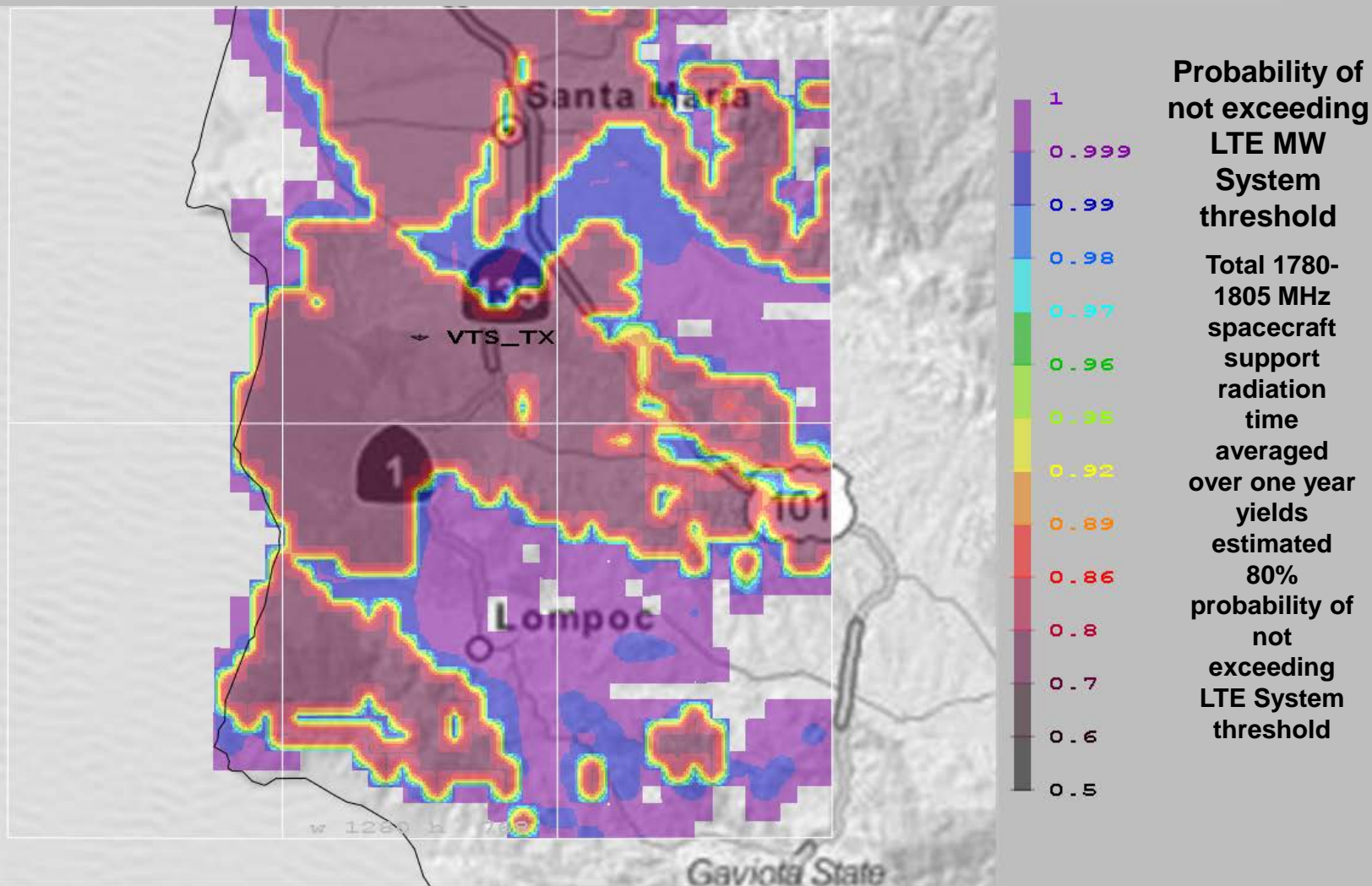
Probability of
not exceeding
LTE MW
System
threshold



Total 1780-
1805 MHz
spacecraft
support
radiation
time
averaged
over one year
yields
estimated
80%
probability of
not
exceeding
LTE System
threshold

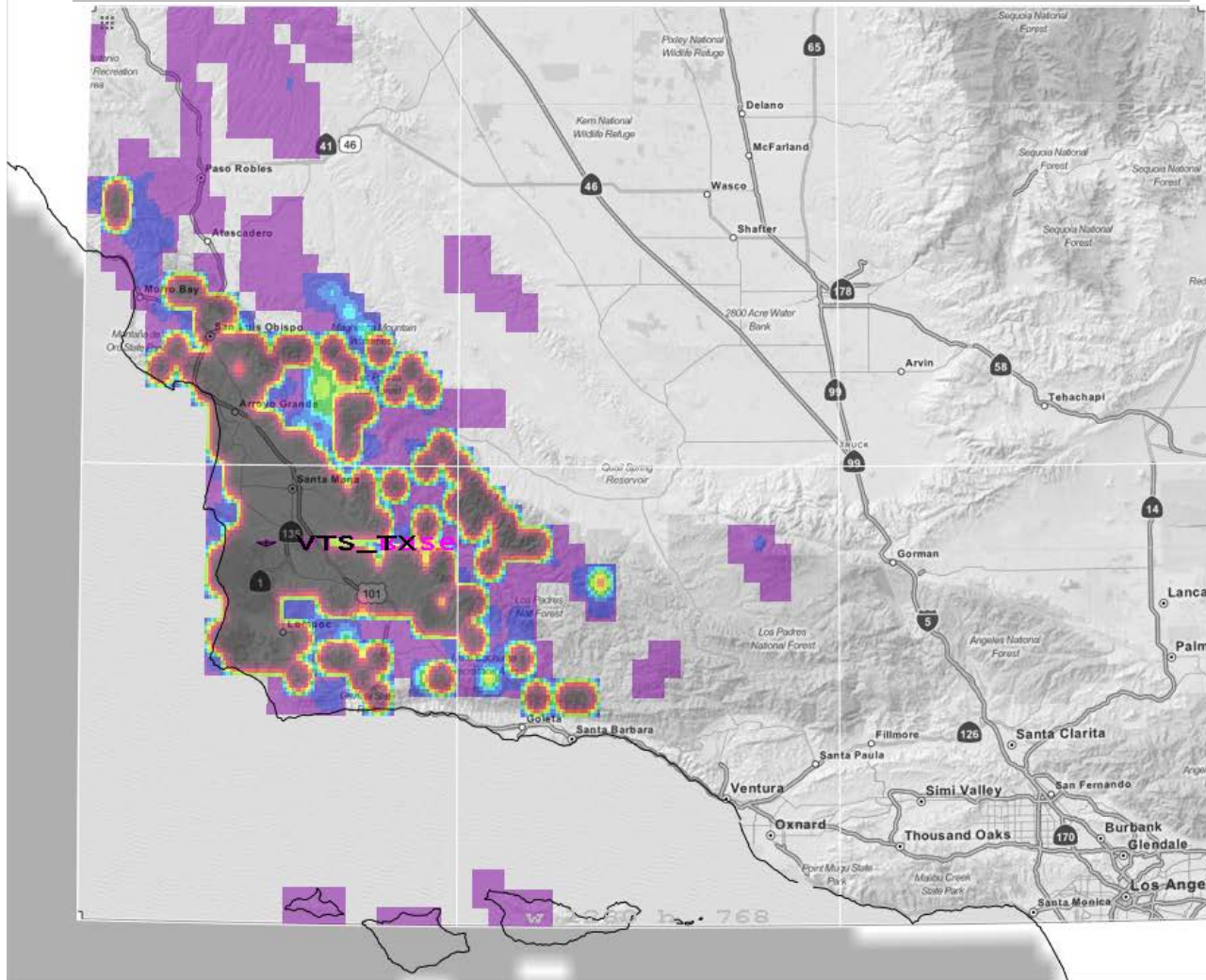
VTSS LTE System Threshold Exceedance, 1780-1805 MHz

1 kW transmitter power, 20 dB attenuation, 1 km grid spacing



VTS LTE System Threshold Exceedance, 1805-1850 MHz

1 kW transmitter power, 5 km grid spacing



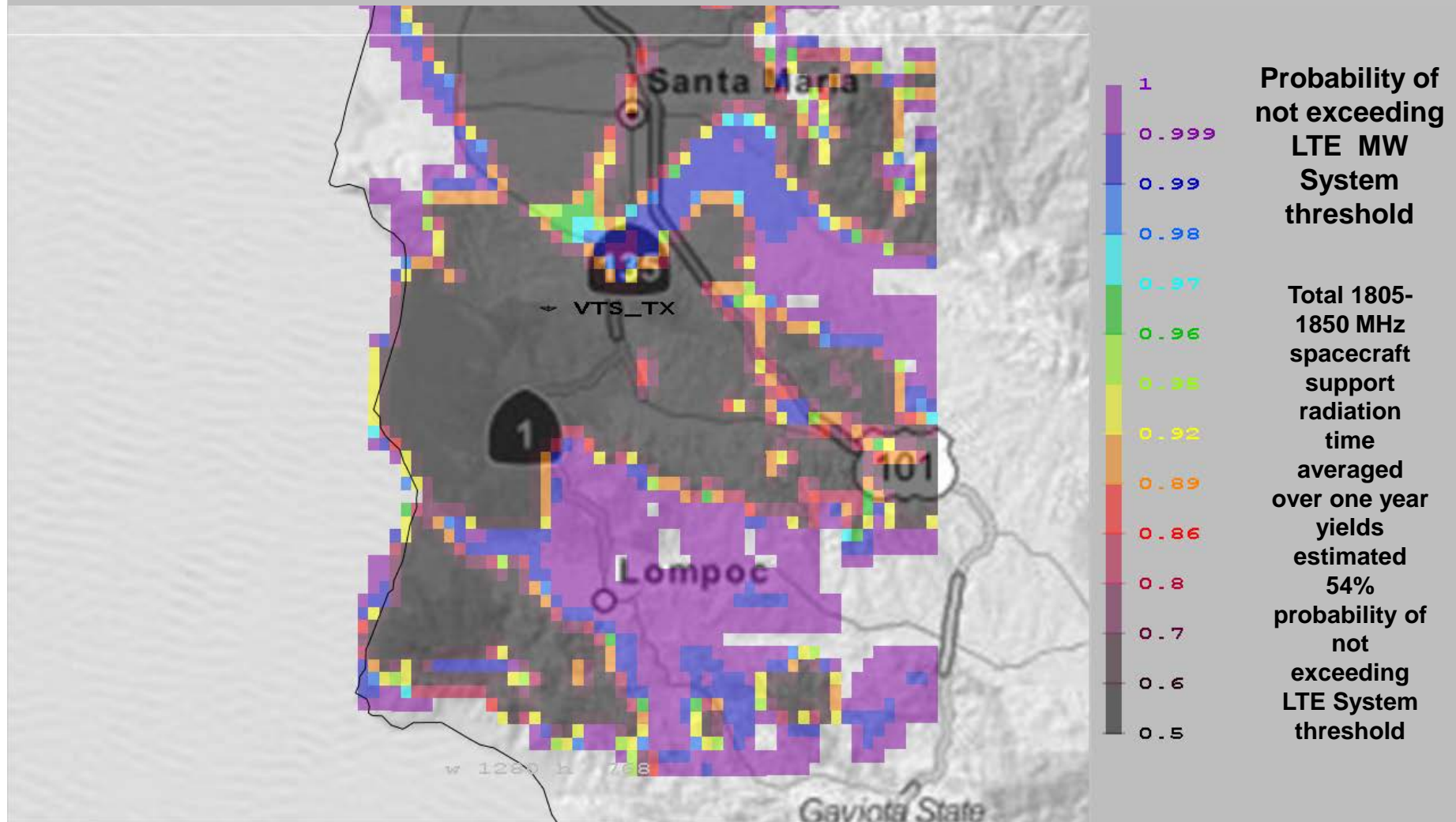
Probability of
not exceeding
LTE MW
System
threshold



Total 1805-
1850 MHz
spacecraft
support
radiation
time
averaged
over one year
yields
estimated
54%
probability of
not
exceeding
LTE System
threshold

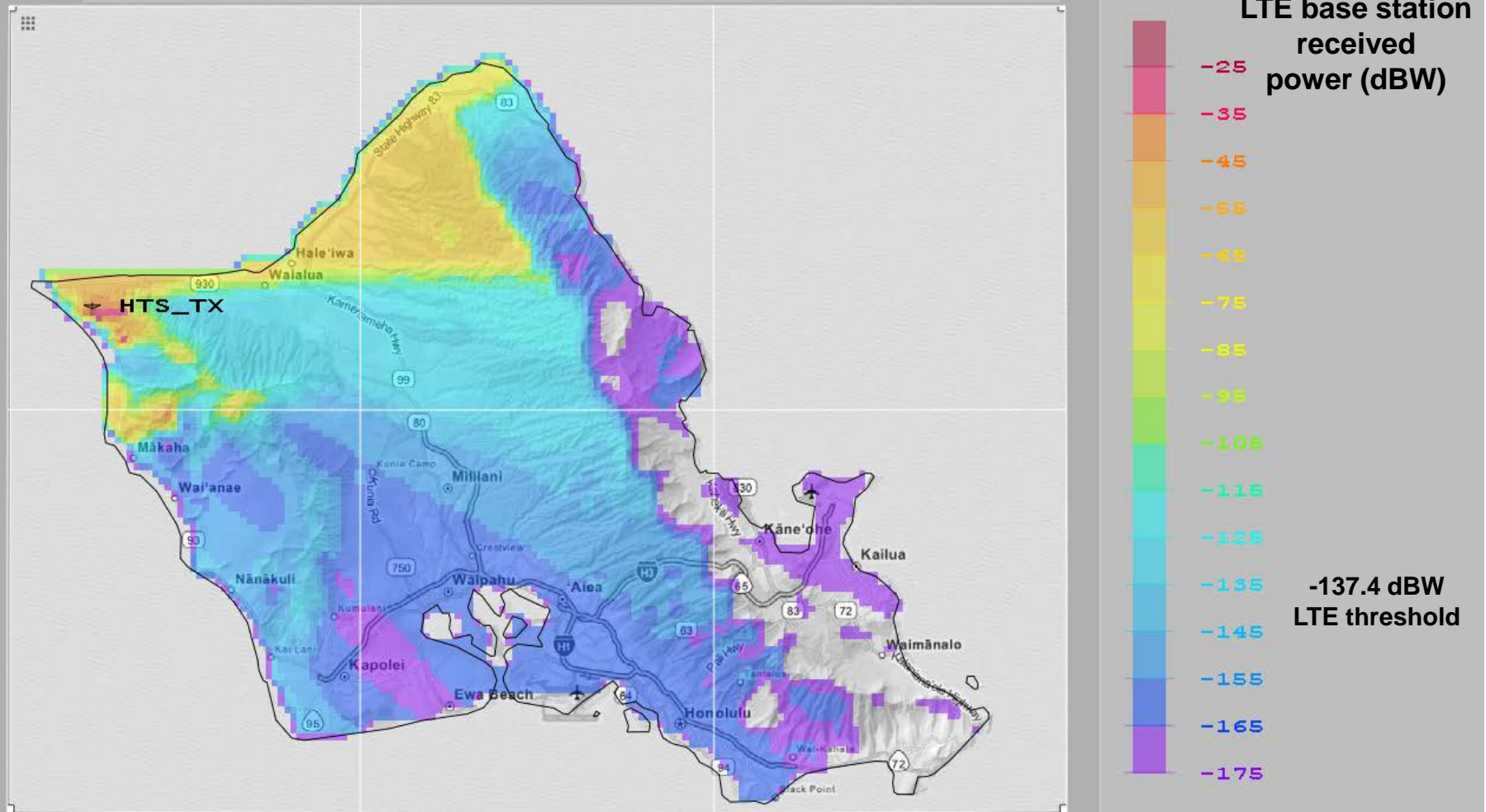
VTS LTE System Threshold Exceedance, 1805-1850 MHz

1 kW transmitter power with 20 dB attenuation, 1 km grid spacing



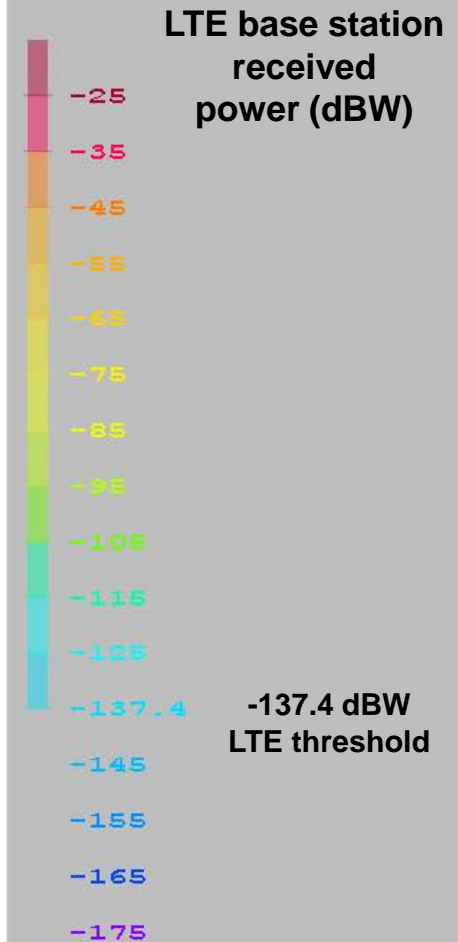
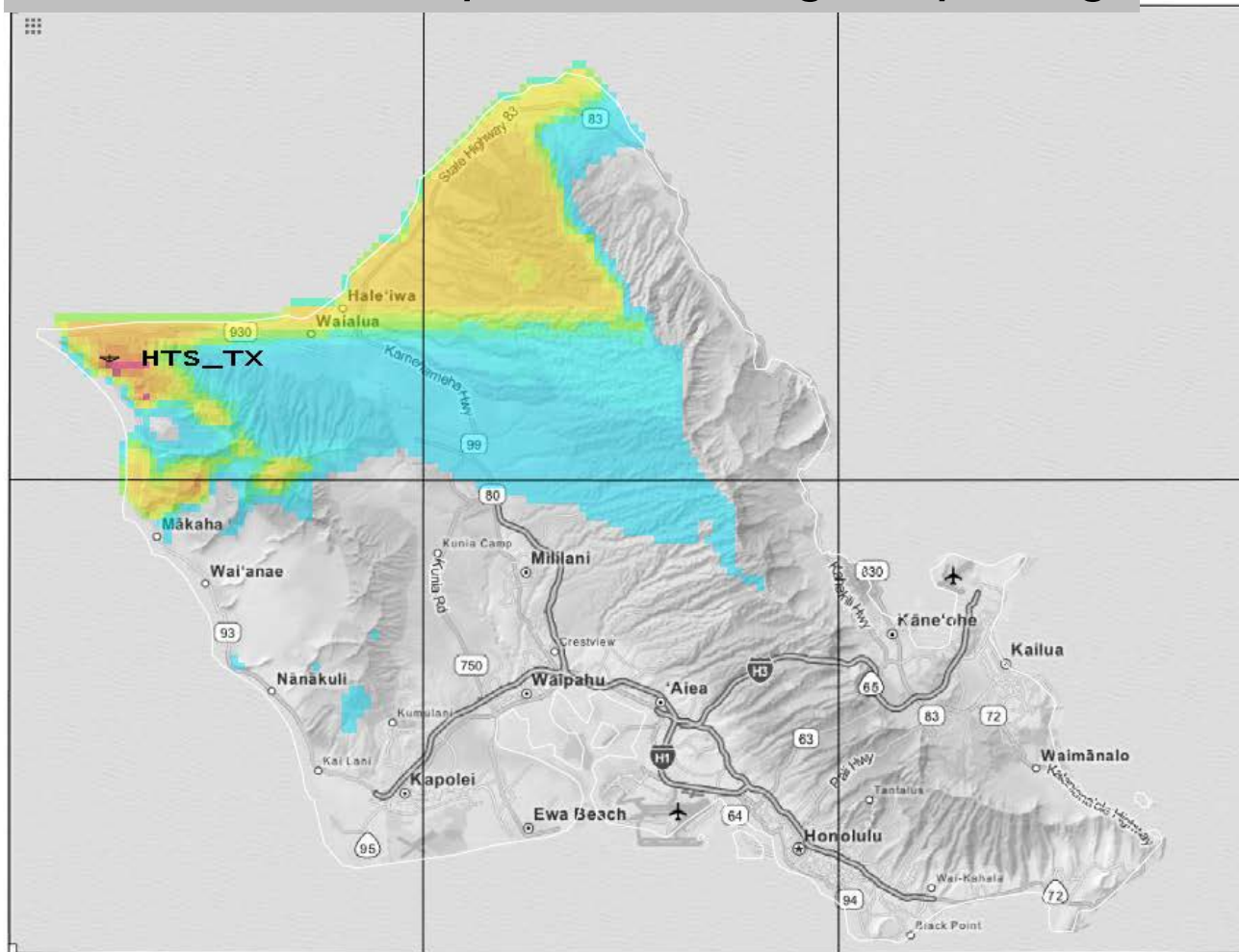
HTS Power Contours

1 kW transmitter power, 1 km grid spacing



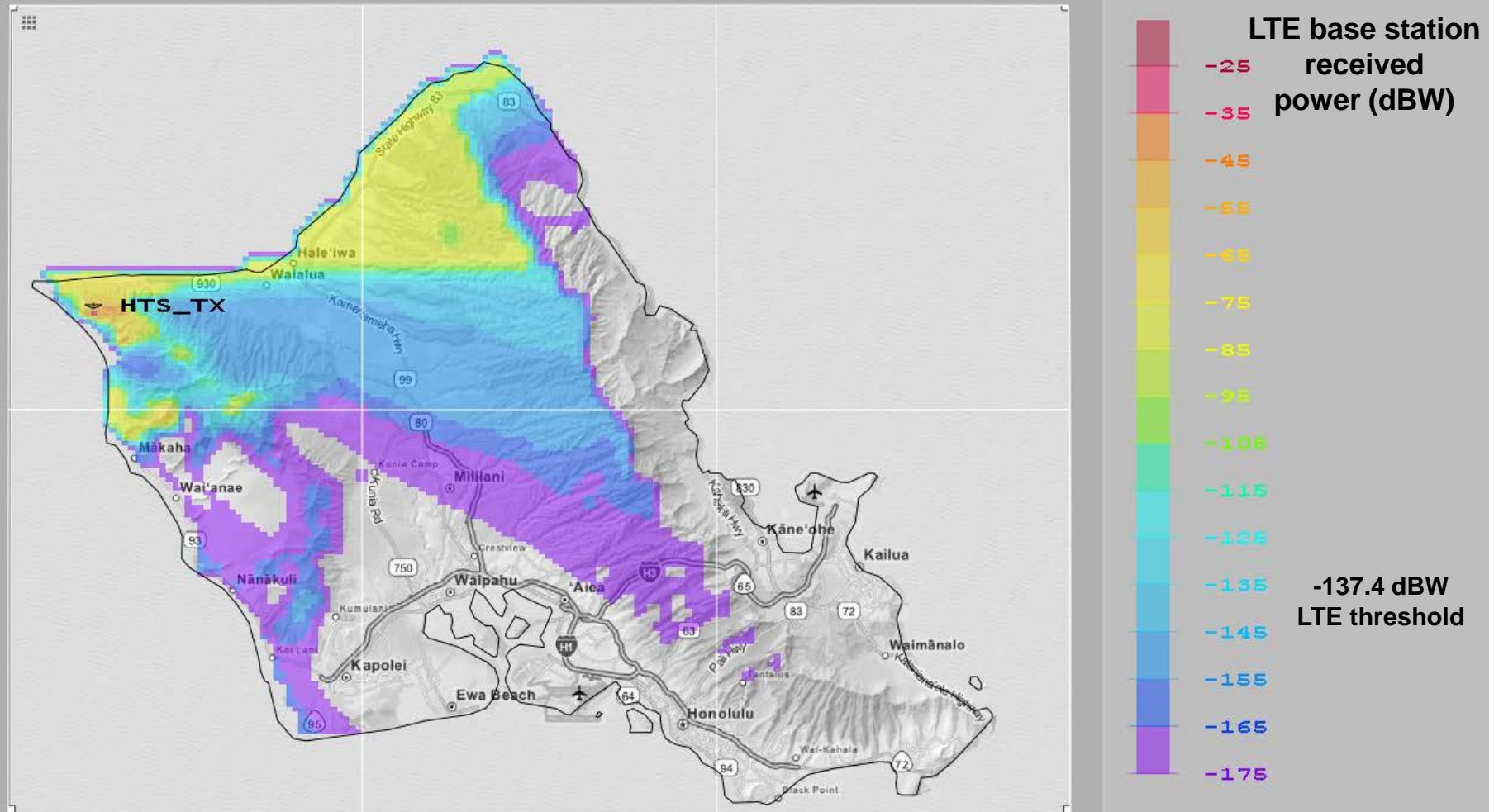
HTS Radiated Power With Natural Terrain in Gray Indicating Power Below Threshold

1 kW transmitter power, 1 km grid spacing



HTS Power Contours

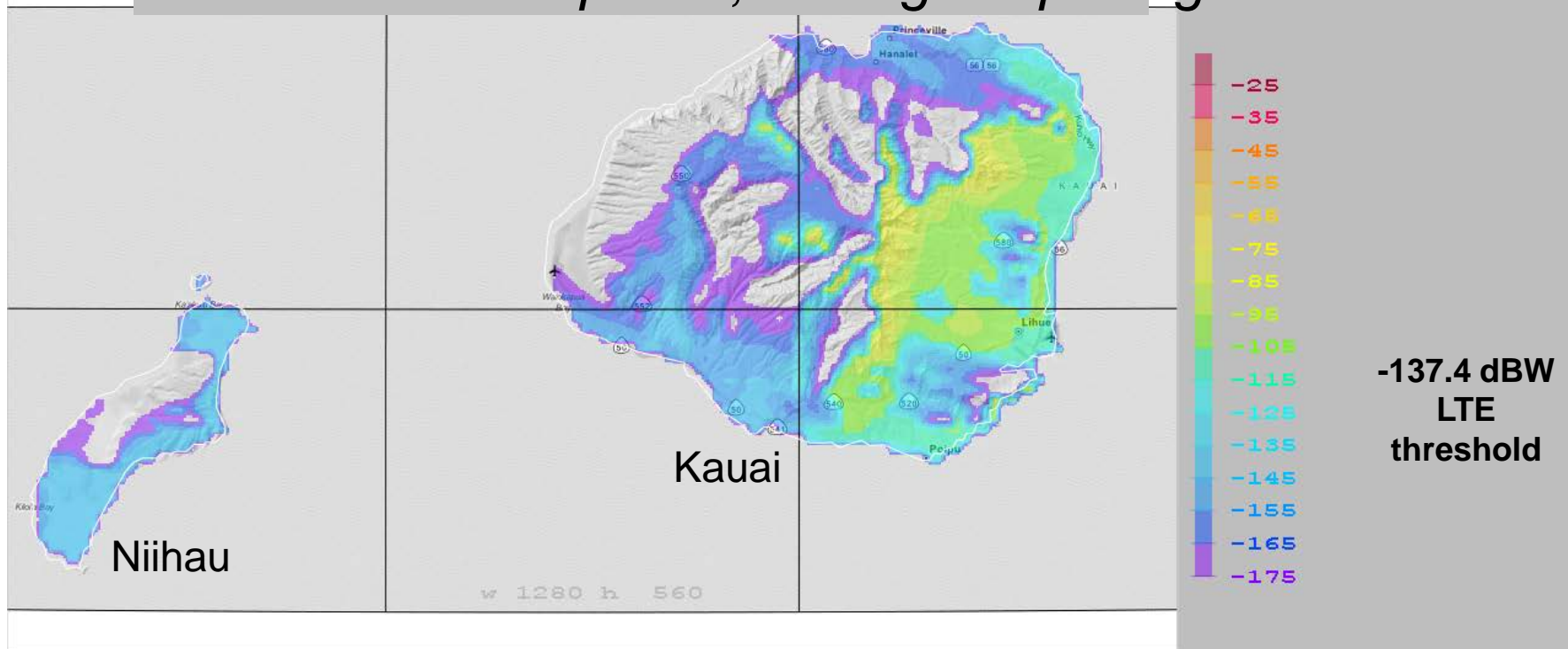
1 kW transmitter power, 20 dB attenuation, 1 km grid spacing



HTS Power Contours

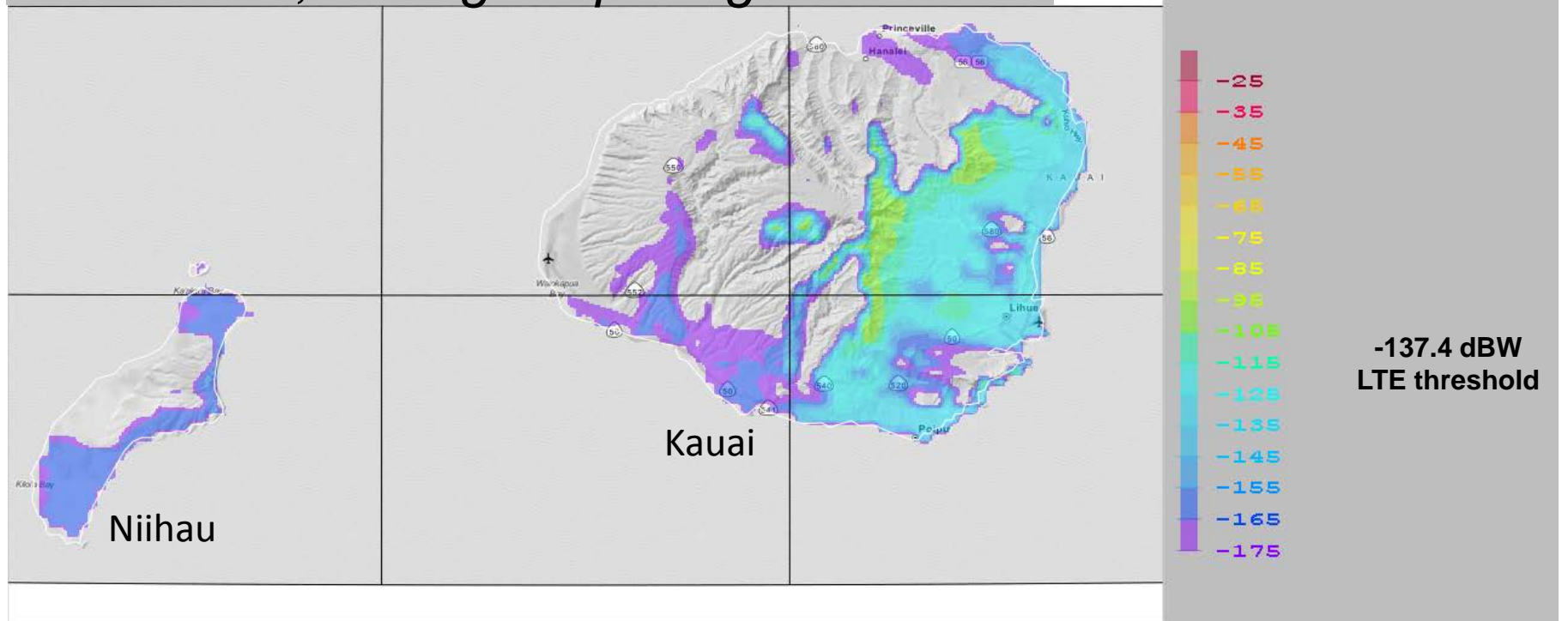
1 kW transmitter power, 1 km grid spacing

LTE base station
received
power (dBW)



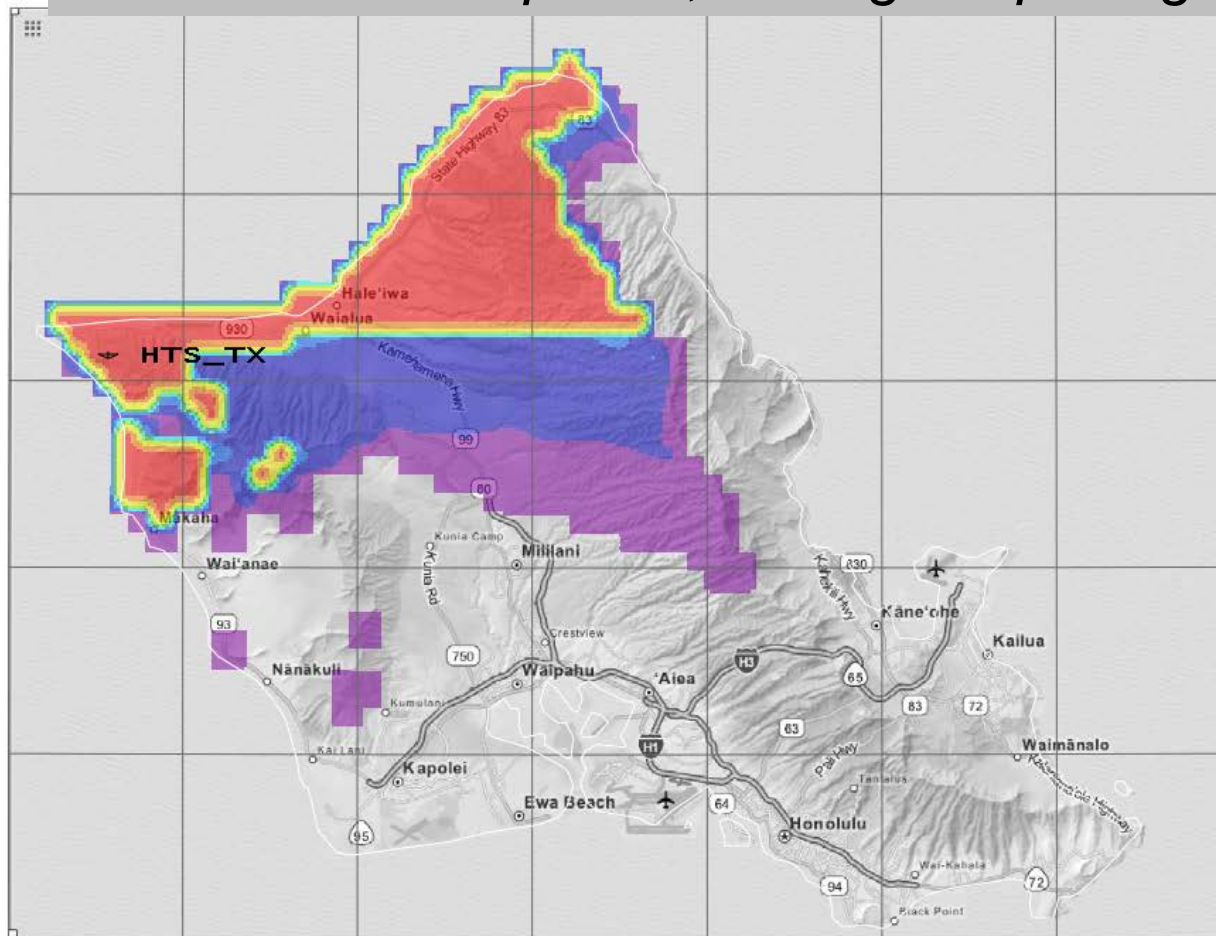
HTS Power Contours

*1 kW transmitter power with 20 dB
attenuation, 1 km grid spacing*



HTS LTE System Threshold Exceedance, 1755-1780 MHz

1 kW transmitter power, 1 km grid spacing



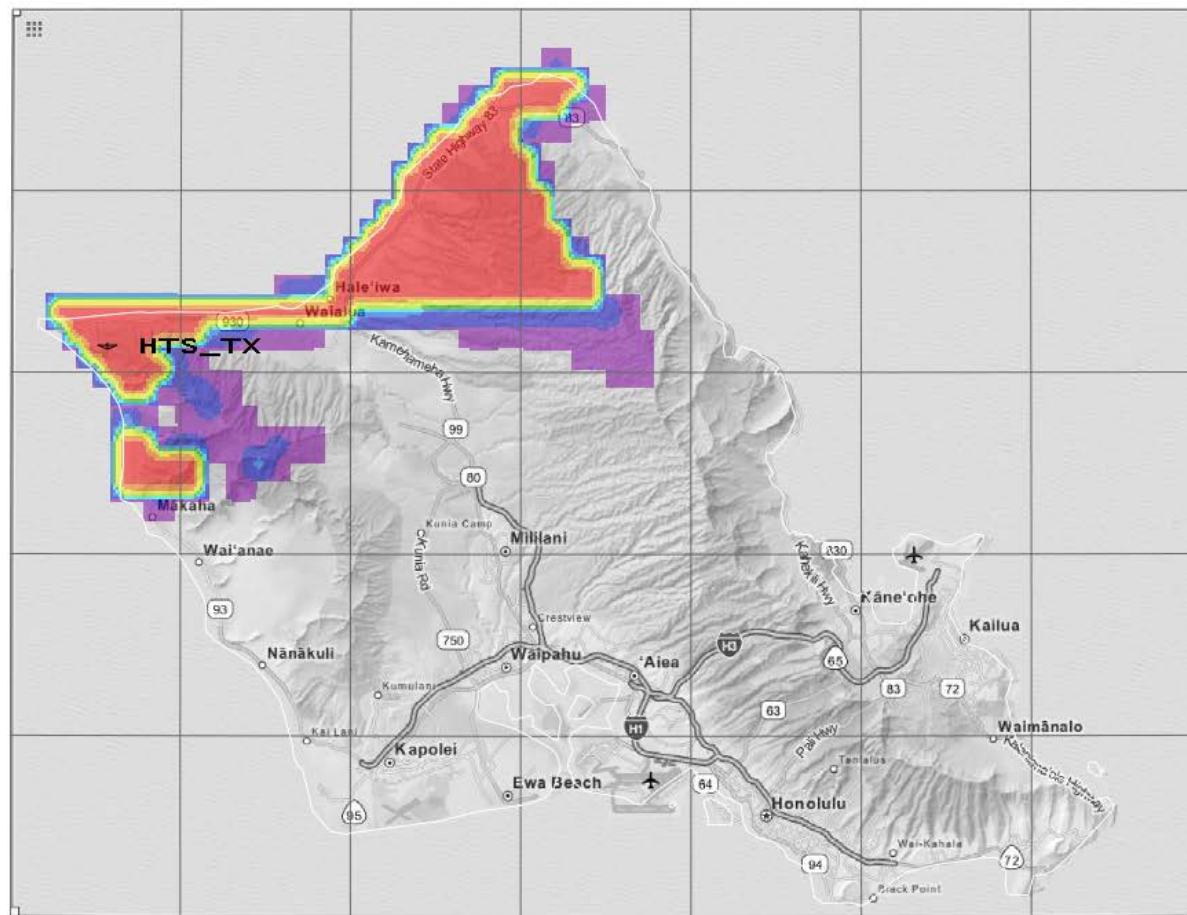
Probability of not
exceeding
LTE MW System
threshold



**Total 1755-
1780 MHz
spacecraft
support
radiation time
averaged over
one year
yields
estimated 87%
probability of
not exceeding
LTE System
threshold**

HTS LTE System Threshold Exceedance, 1755-1780 MHz

1 kW transmitter power, 20 dB attenuation, 1 km grid spacing



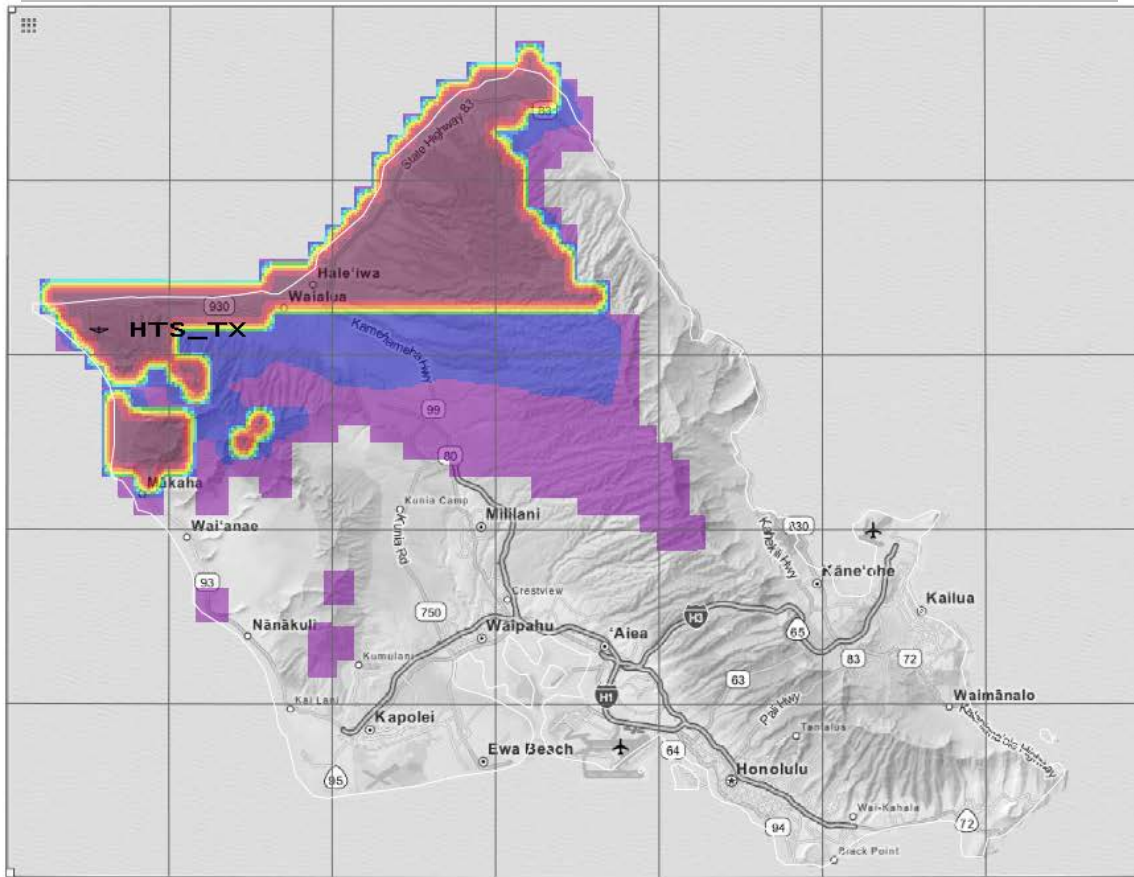
Probability of not
exceeding
LTE MW System
threshold

Total 1755-
1780 MHz
spacecraft
support
radiation time
averaged over
one year
yields
estimated
87%
probability of
not exceeding
LTE System
threshold



HTS LTE System Threshold Exceedance, 1780-1805 MHz

1 kW transmitter power, 1 km grid spacing



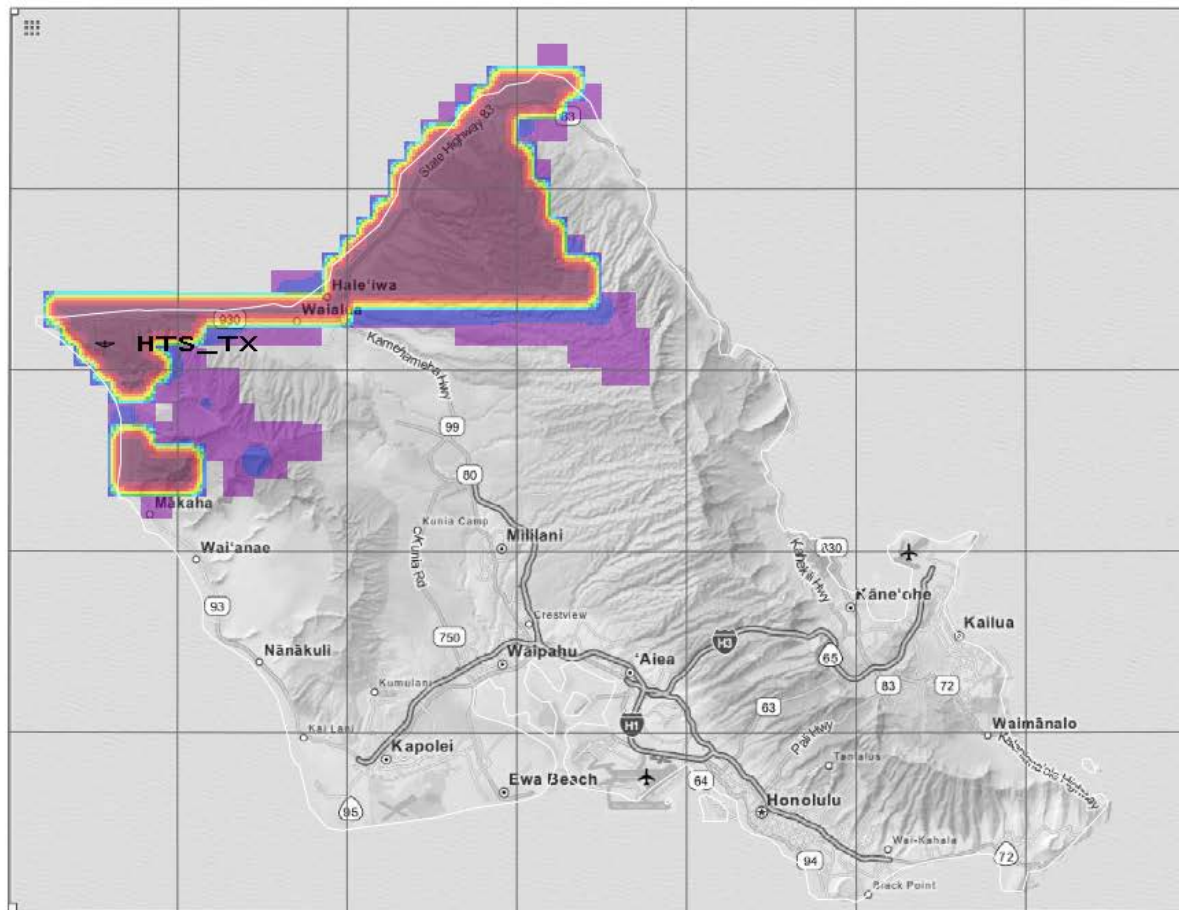
**Probability of not exceeding
LTE MW System
threshold**

Total 1780-1805 MHz for spacecraft support radiation time averaged over one year yields estimated 78% probability of not exceeding LTE System threshold

Units: s

HTS LTE System Threshold Exceedance, 1780-1805 MHz

1 kW transmitter power, 20 dB attenuation, 1 km grid spacing



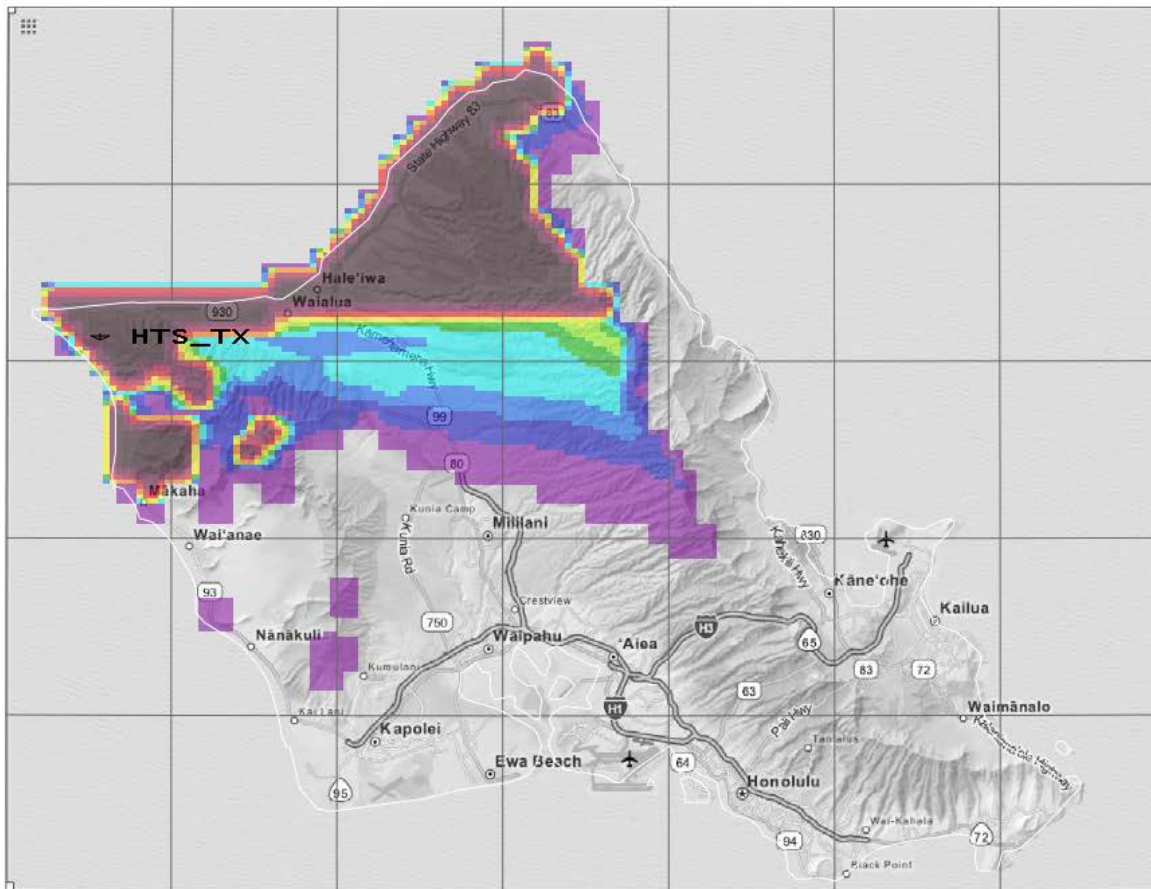
Probability of not
exceeding
LTE MW System
threshold

Total 1780-1805
MHz spacecraft
support
radiation time
averaged over
one year yields
estimated 78%
probability of
not exceeding
LTE System
threshold

Units: s

HTS LTE System Threshold Exceedance, 1805-1850 MHz

1 kW transmitter power, 1 km grid spacing

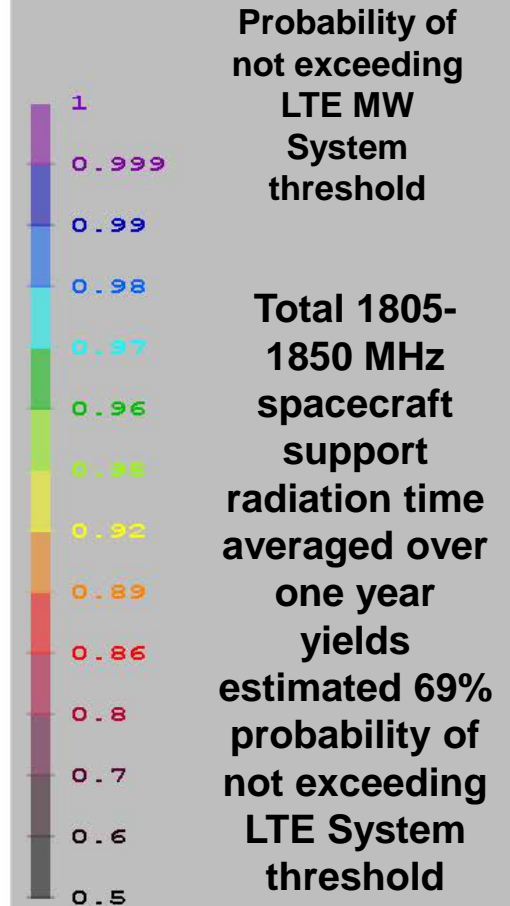
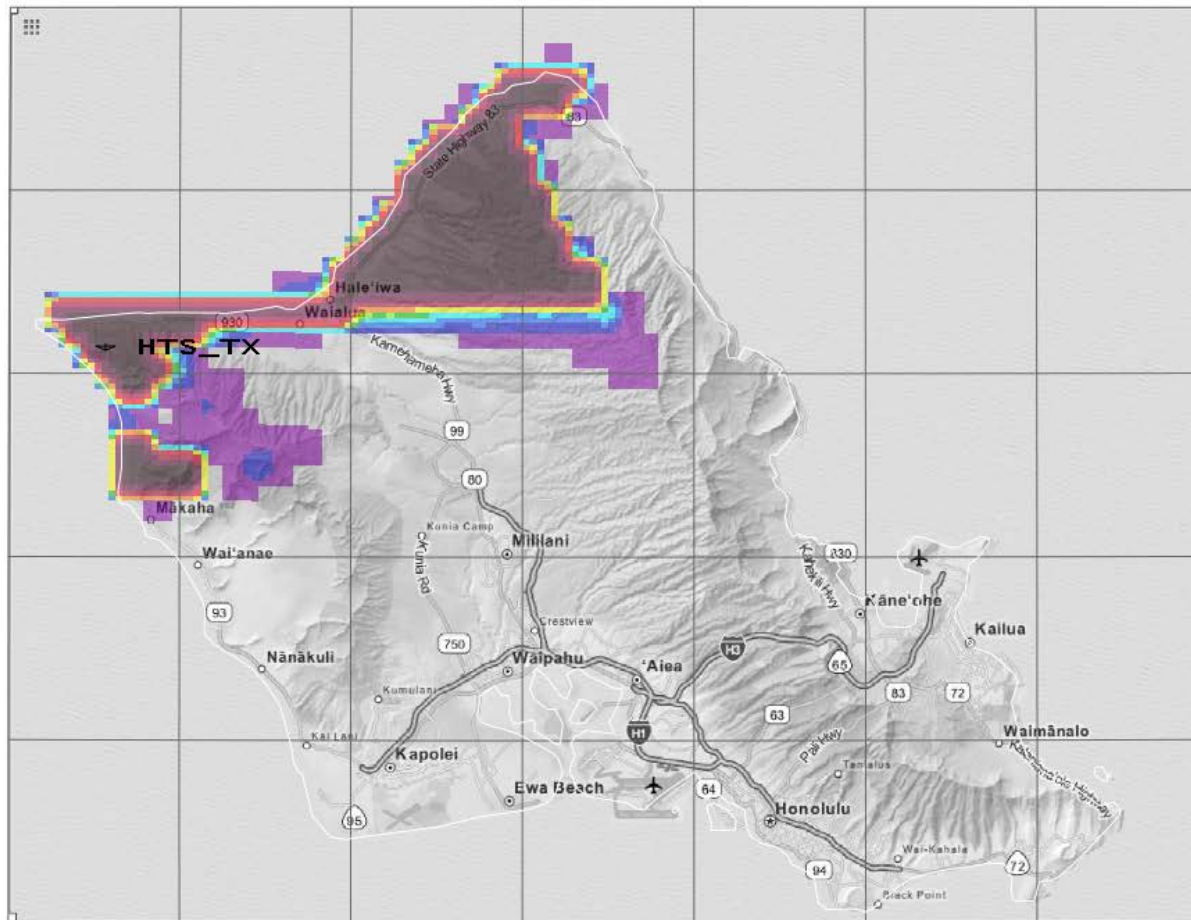


Probability of not exceeding LTE MW System threshold

**Total 1805-
1850 MHz
spacecraft
support
radiation time
averaged over
one year
yields
estimated 69%
probability of
not exceeding
LTE System
threshold**

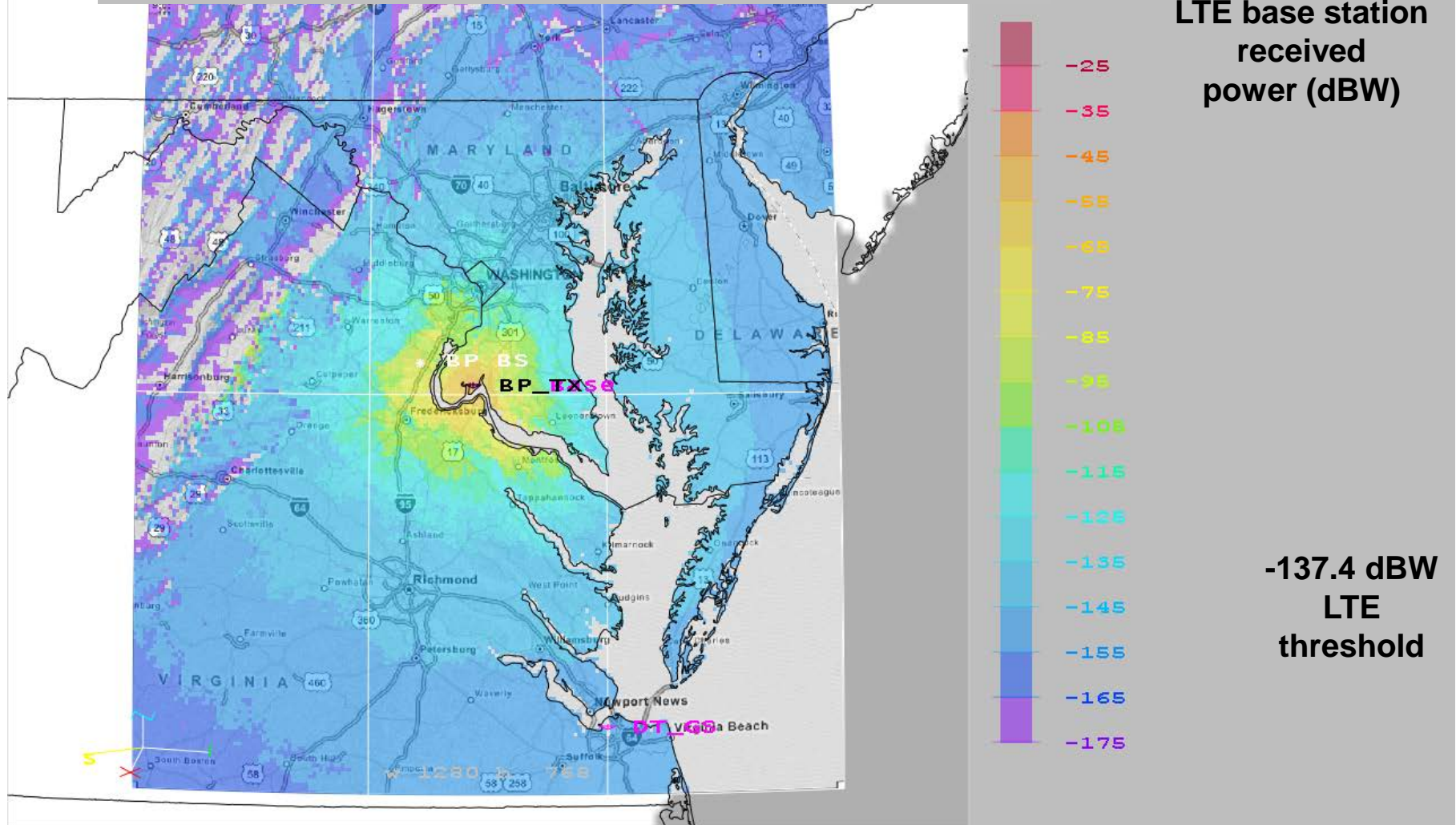
HTS LTE System Threshold Exceedance, 1805-1850 MHz

1 kW transmitter power, 20 dB attenuation, 1 km grid spacing



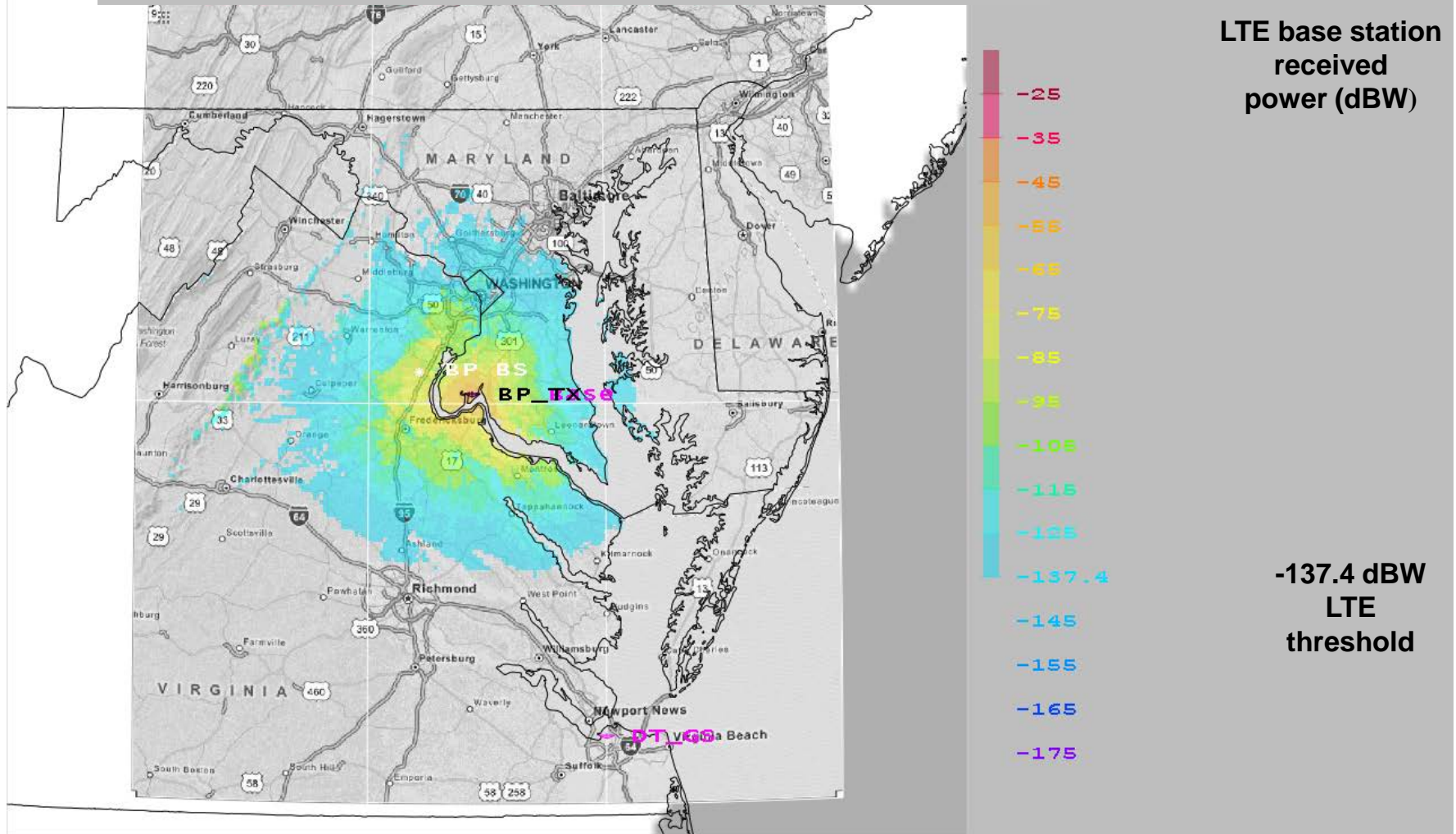
BPTF Power Contours

300W transmitter power, 5 km grid spacing



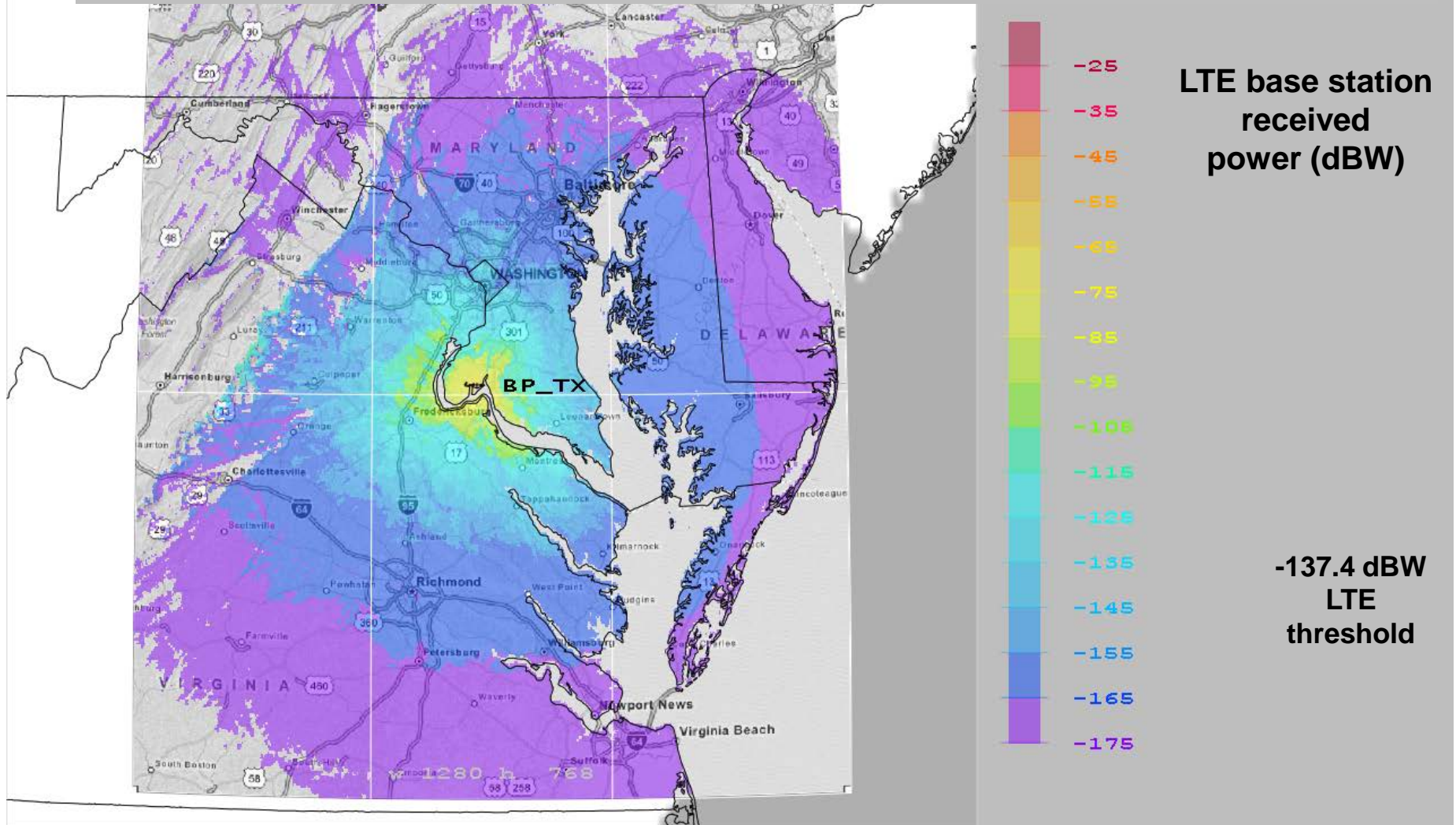
BPTF Radiated Power With Natural Terrain in Gray Indicating Power Below Threshold

300W transmitter power, 5 km grid spacing



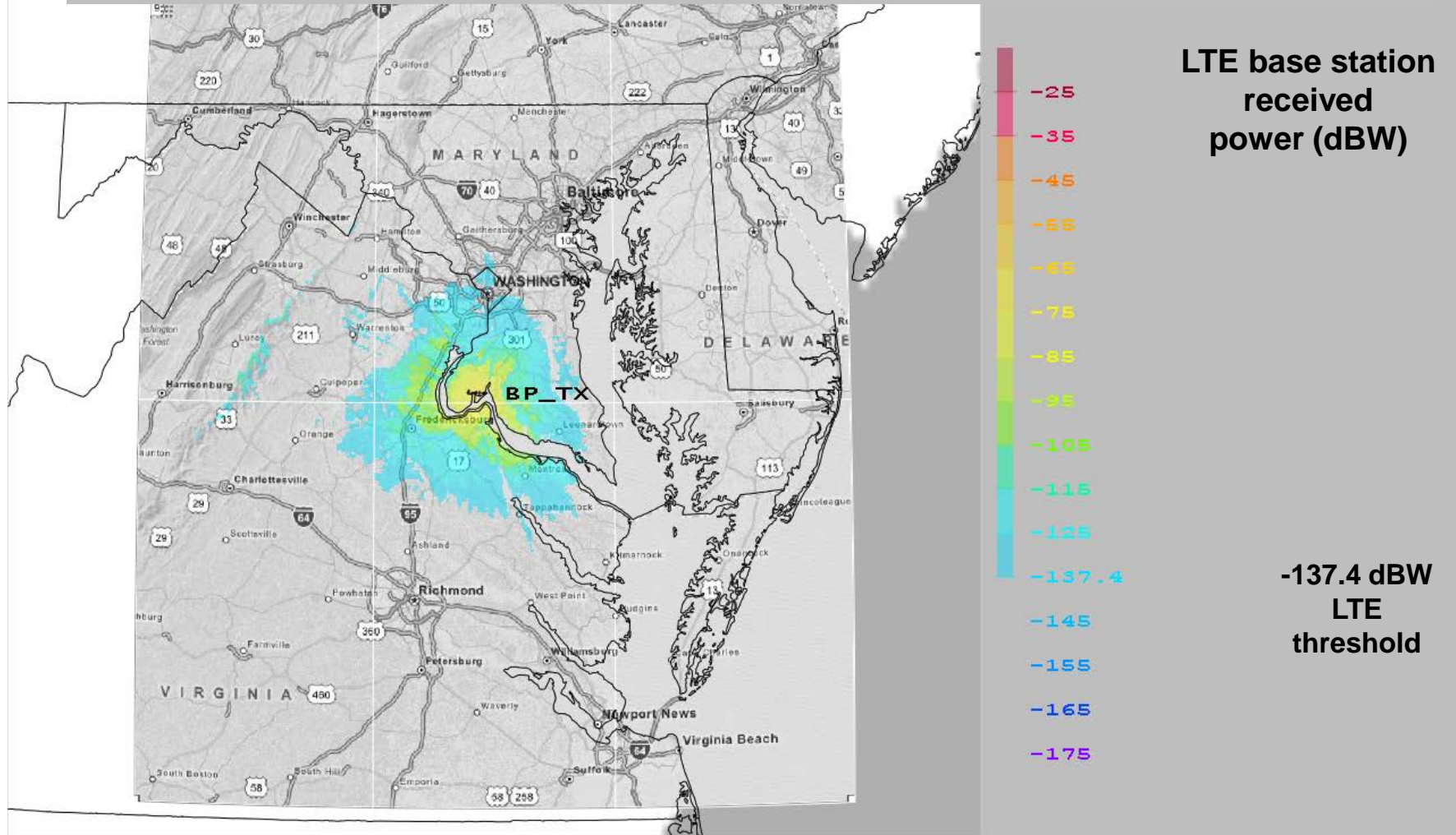
BPTF Power Contours

300W transmitter power, 20 dB attenuation, 5 km grid spacing



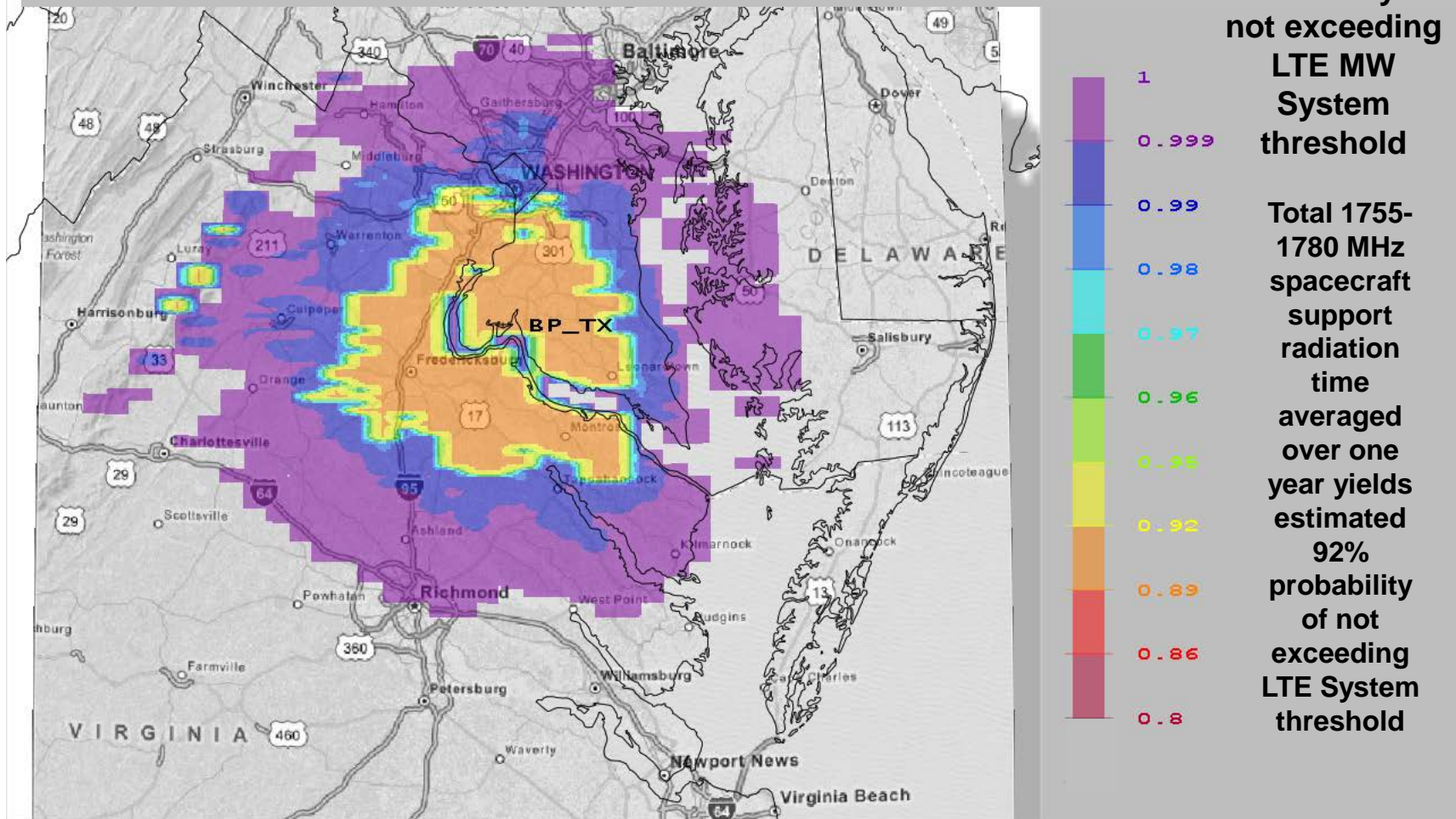
BPTF Radiated Power With Natural Terrain in Gray Indicating Power Below Threshold

300W transmitter power, 20 dB attenuation, 5 km grid spacing



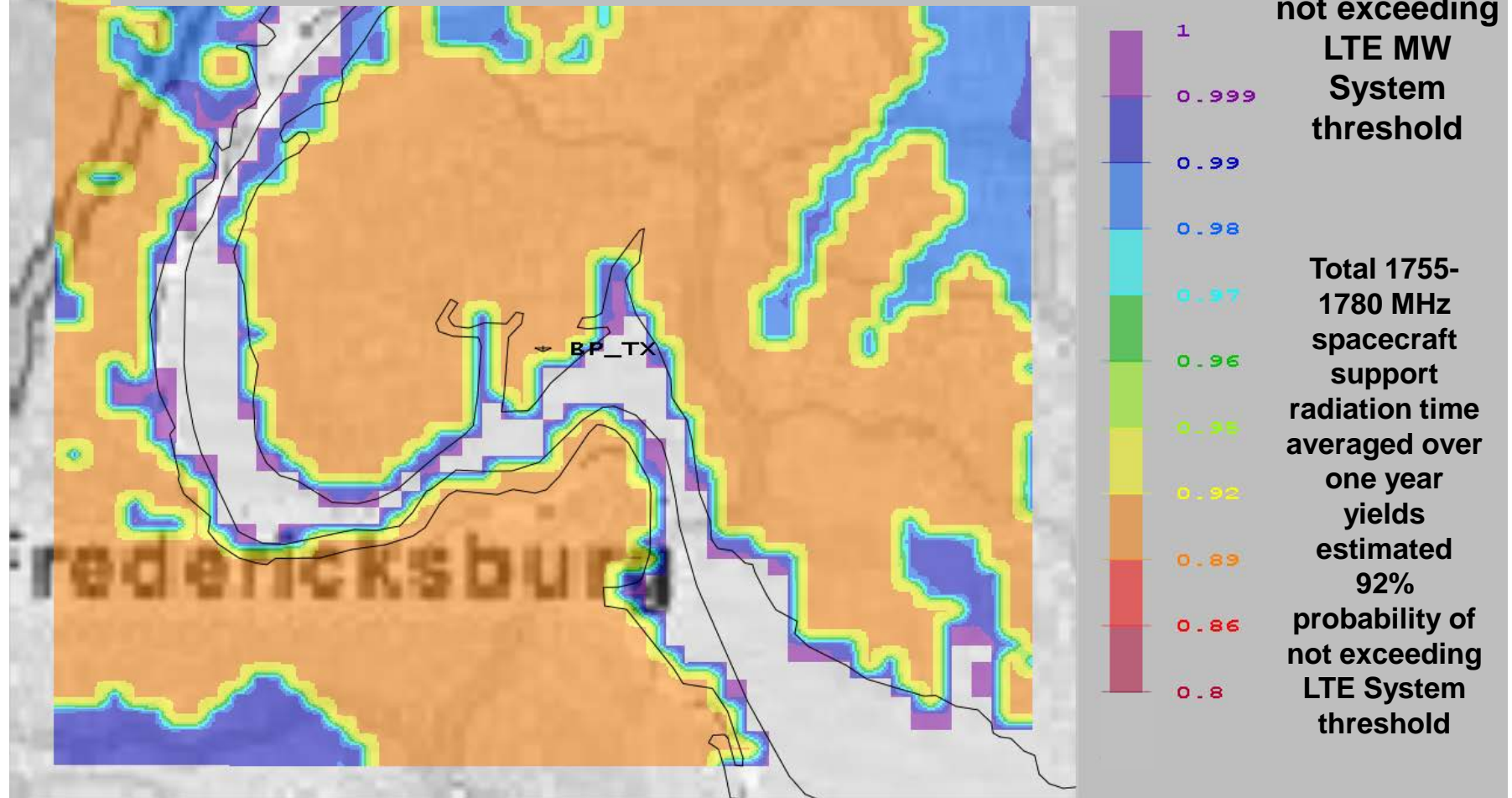
BPTF LTE System Threshold Exceedance, 1755-1780 MHz

300W transmitter power, 5 km grid spacing, one satellite not included



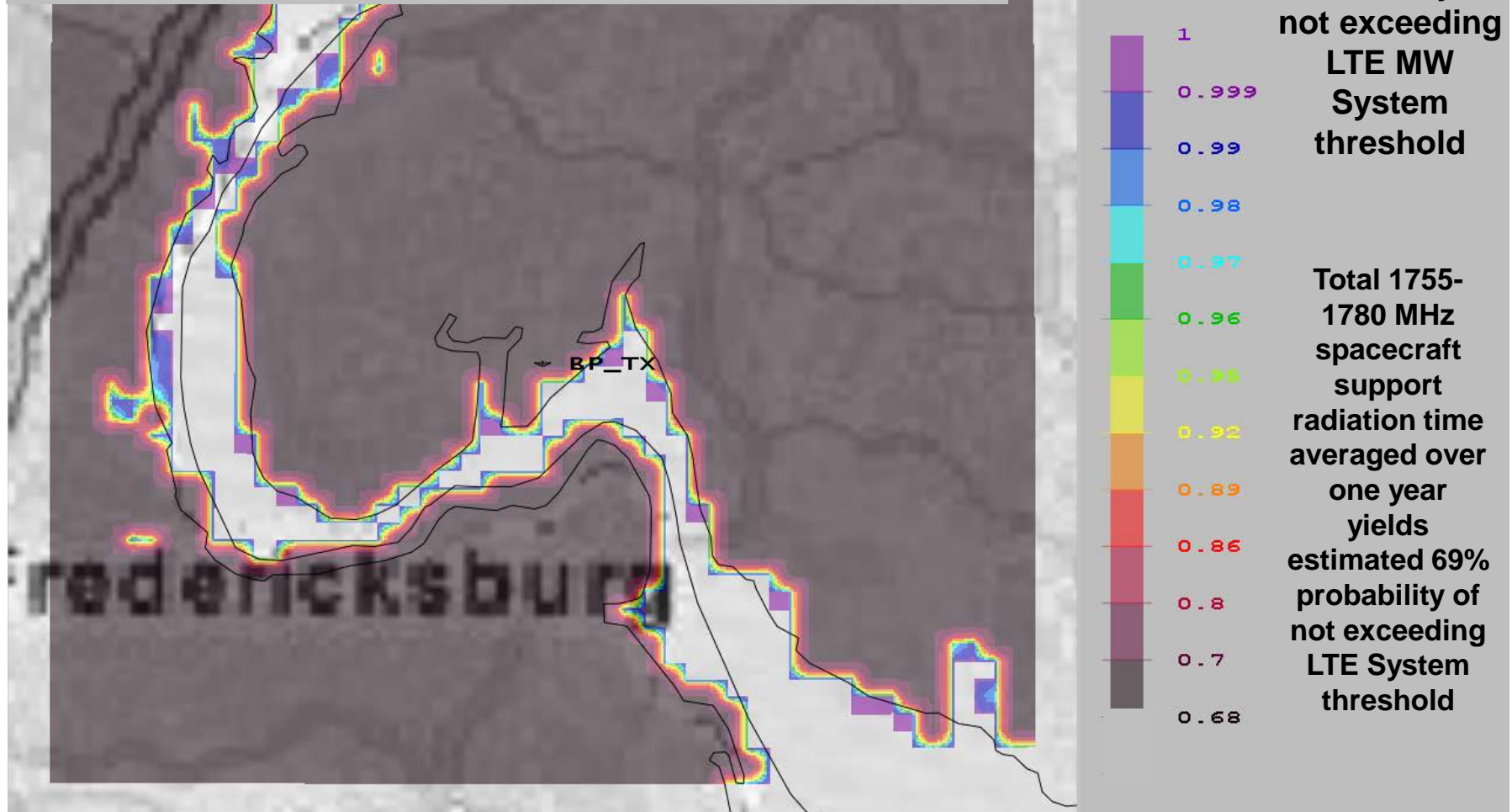
BPTF LTE System Threshold Exceedance, 1755-1780 MHz

*300W transmitter power, 20 dB attenuation
1 km grid spacing, one satellite not included*



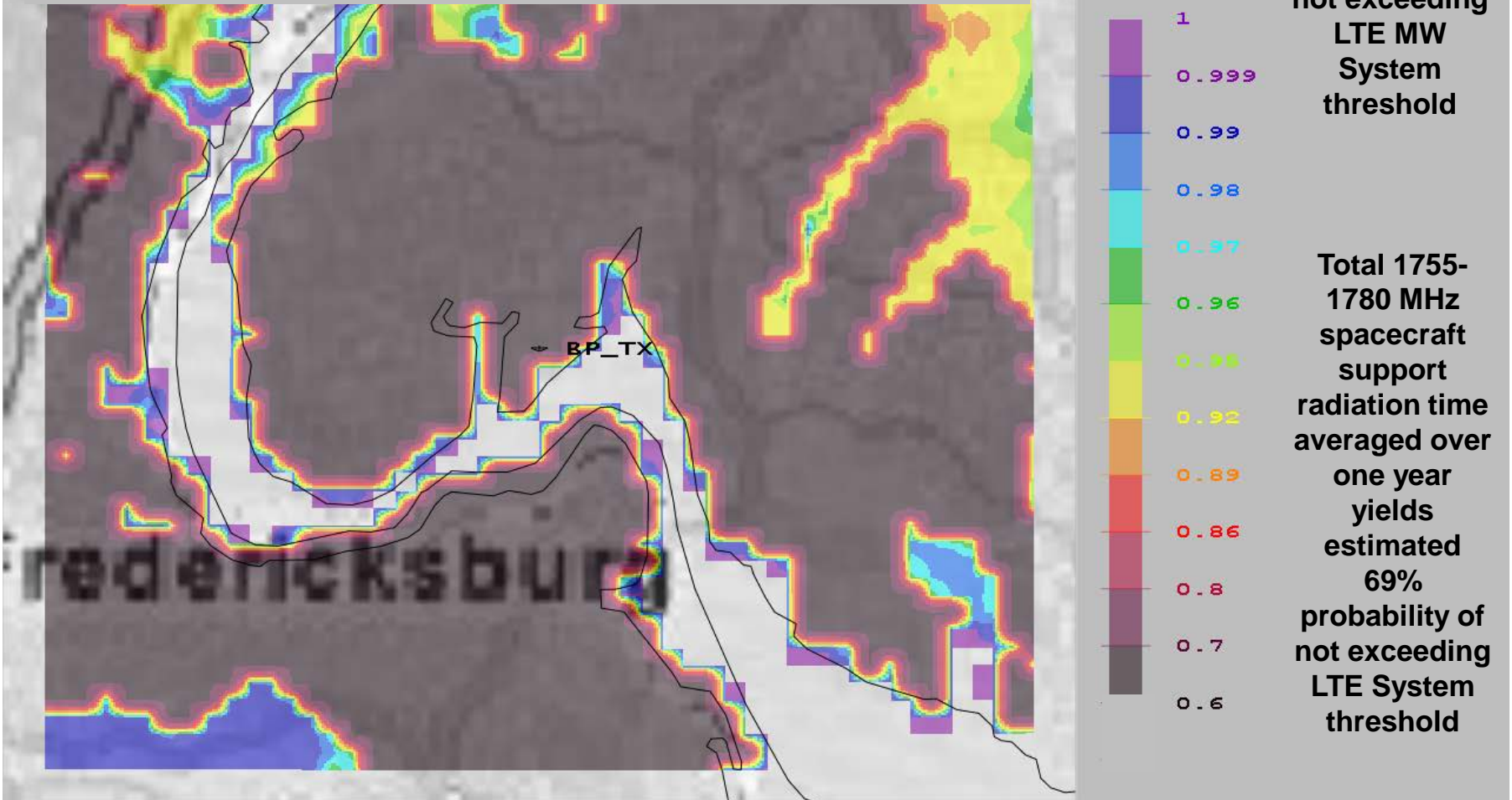
BPTF LTE System Threshold Exceedance, 1755-1780 MHz

*300W transmitter power, 1 km grid spacing,
all satellites included*



BPTF LTE System Threshold Exceedance, 1755-1780 MHz

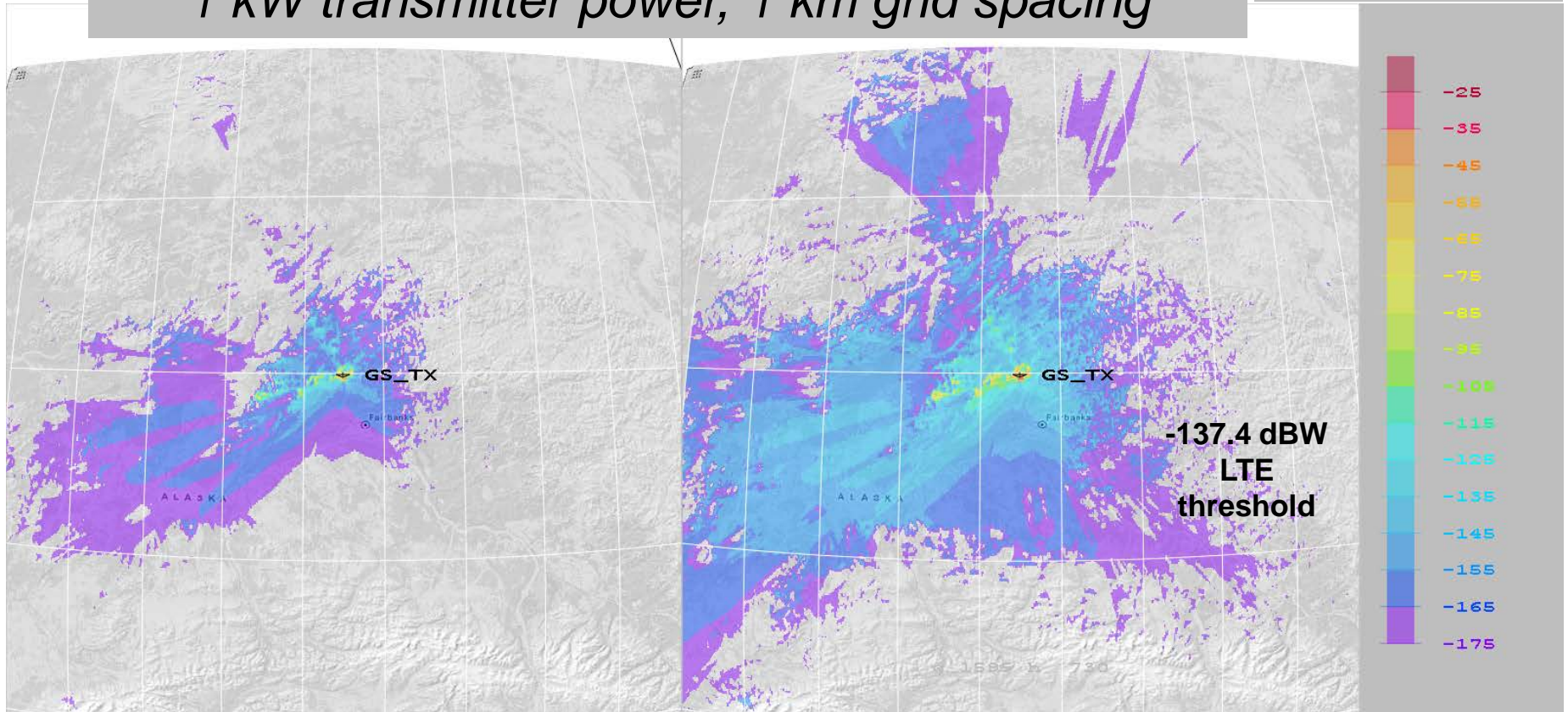
*300W transmitter power, 20 dB attenuation,
1 km grid spacing, all satellites included*



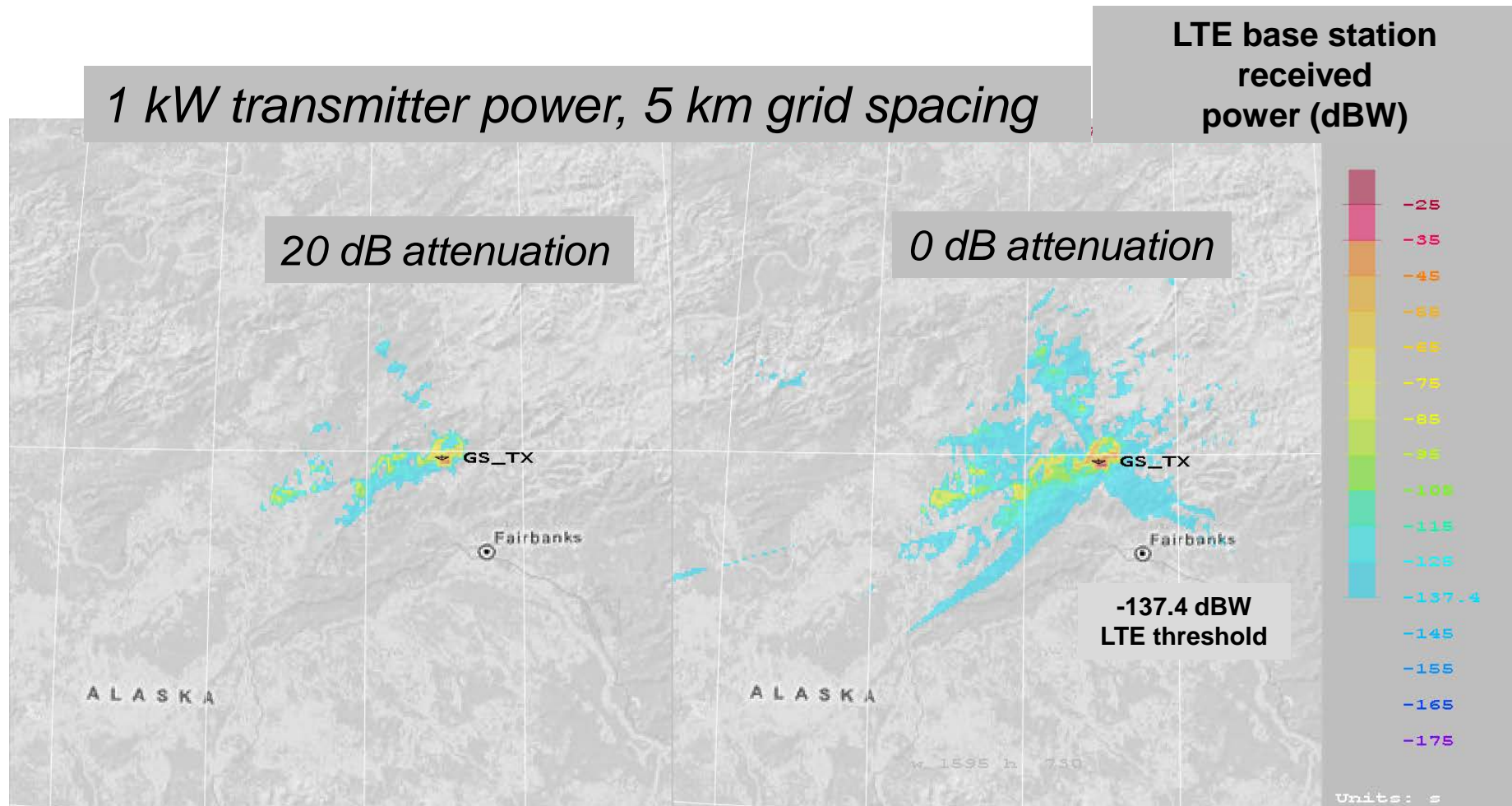
FB, AK Power Contours

1 kW transmitter power, 1 km grid spacing

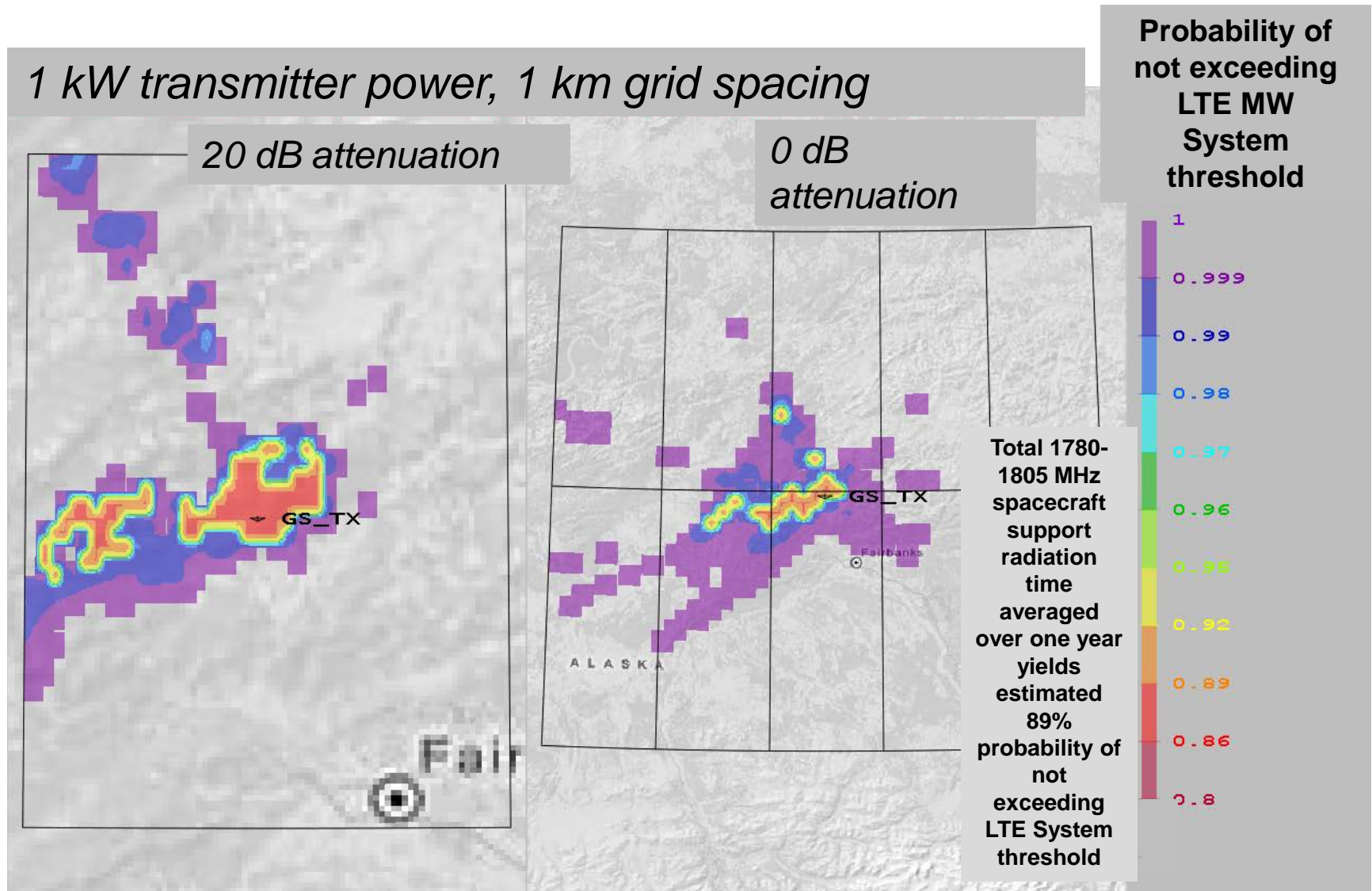
LTE base station
received
power (dBW)



FB, AK Radiated Power With Natural Terrain in Gray Indicating Power Below Threshold



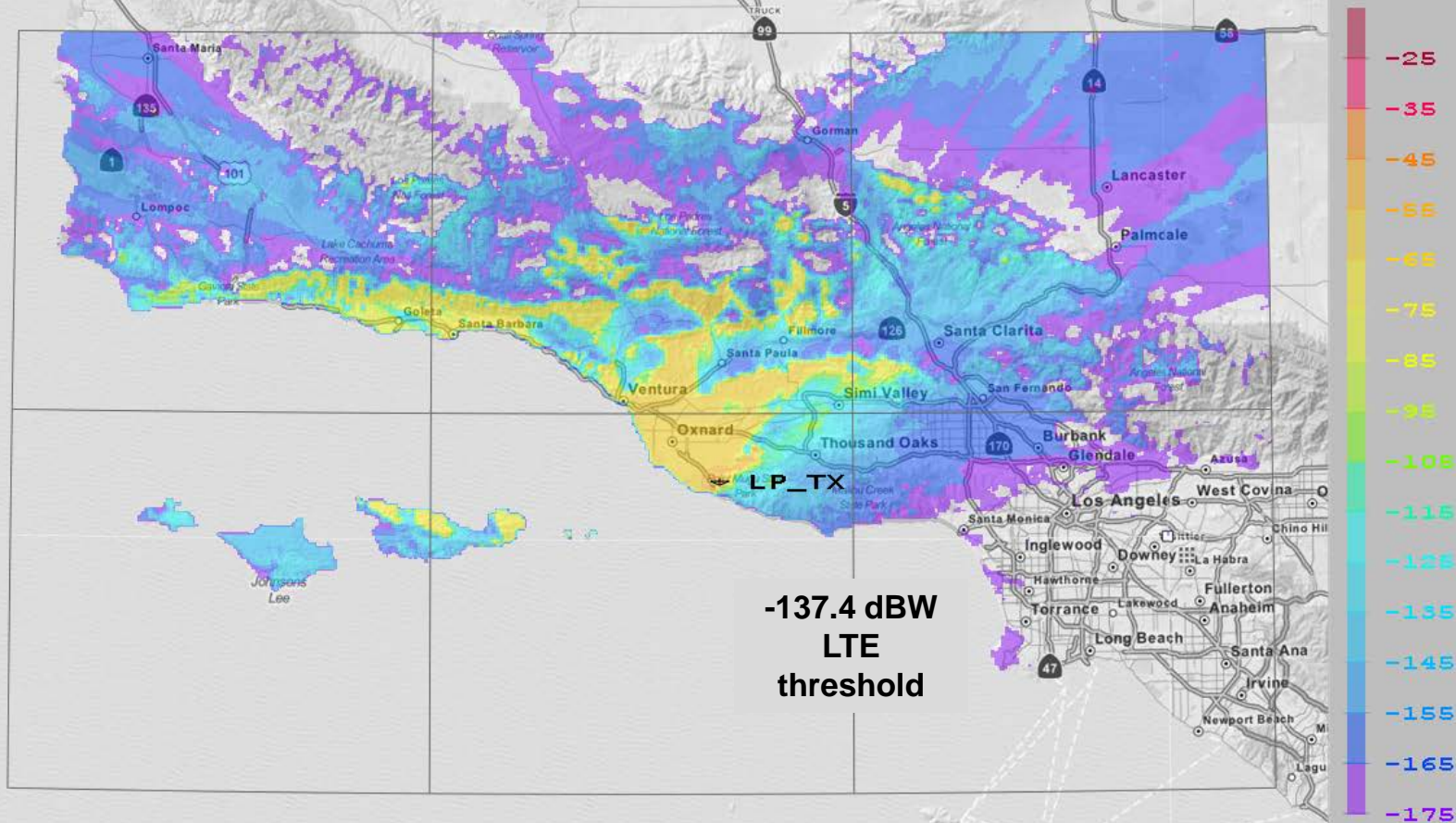
FB, AK LTE System Threshold Exceedance, 1780-1805 MHz



LP, CA Power Contours

1 kW transmitter power, 5 km grid spacing

LTE base station
received
power (dBW)

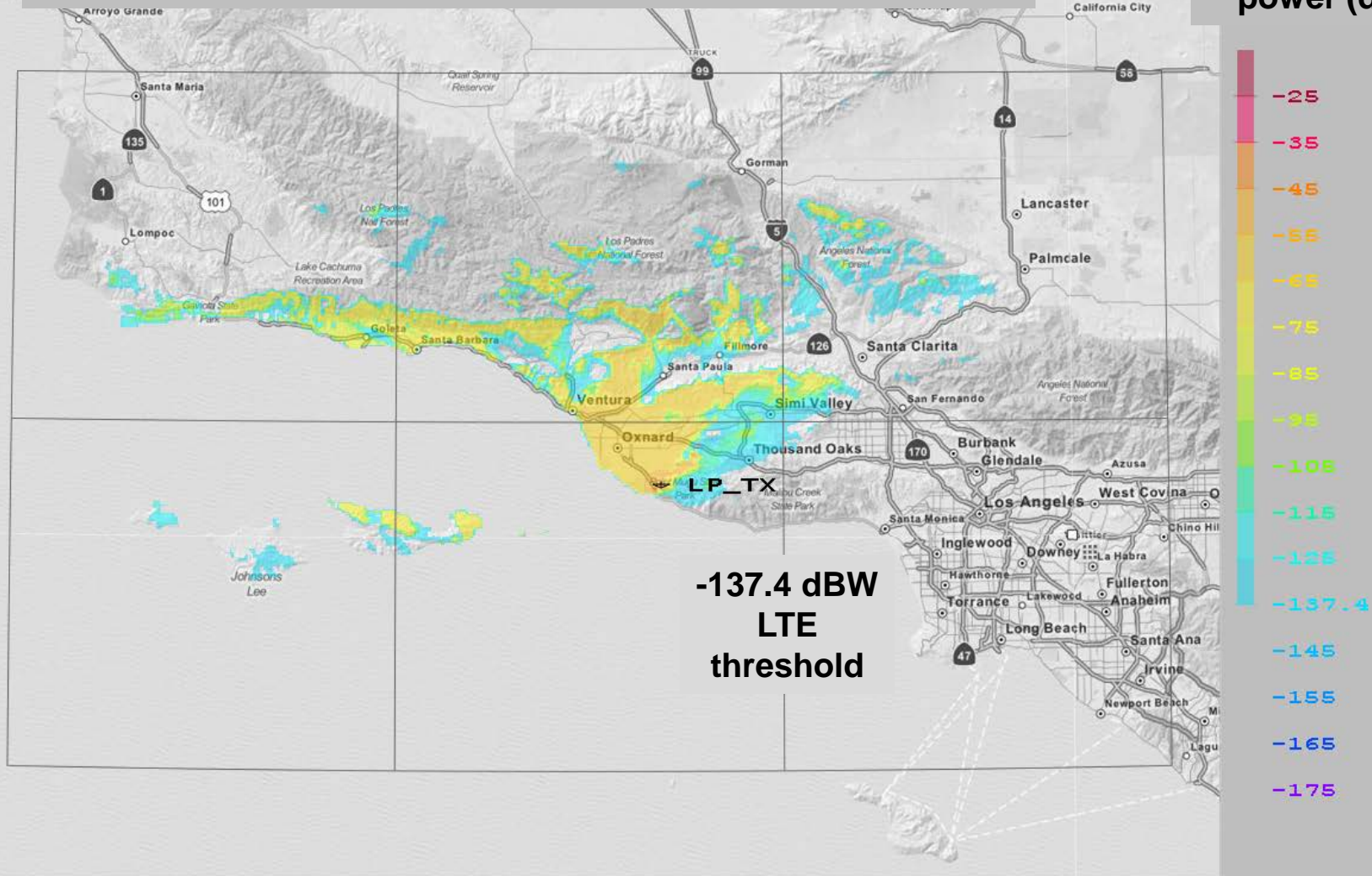


-137.4 dBW
LTE
threshold

LP, CA Radiated Power With Natural Terrain in Gray Indicating Power Below Threshold

1 kW transmitter power, 5 km grid spacing

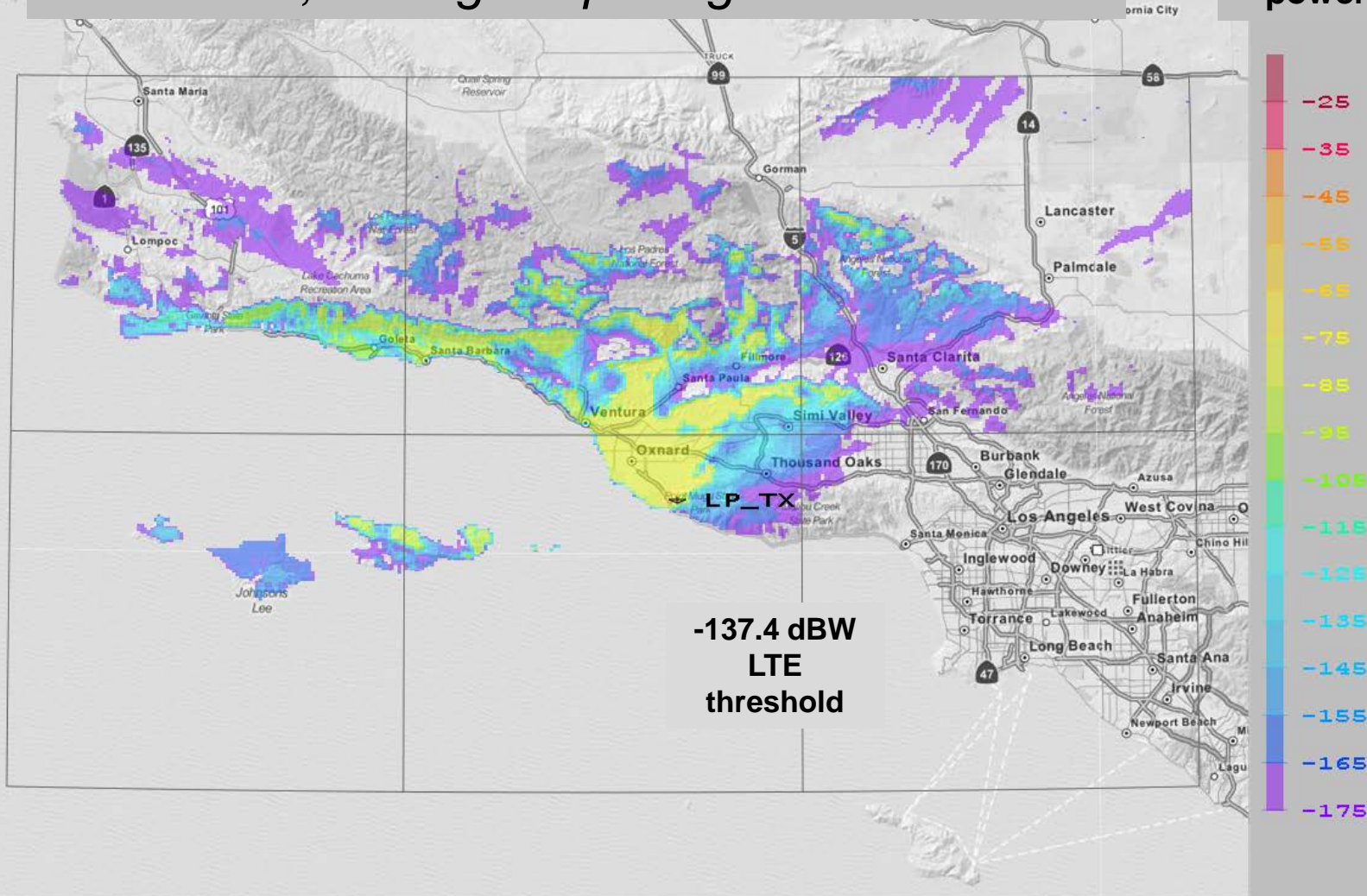
LTE base station
received
power (dBW)



LP, CA Power Contours

*1 kW transmitter power with 20 dB
attenuation, 5 km grid spacing*

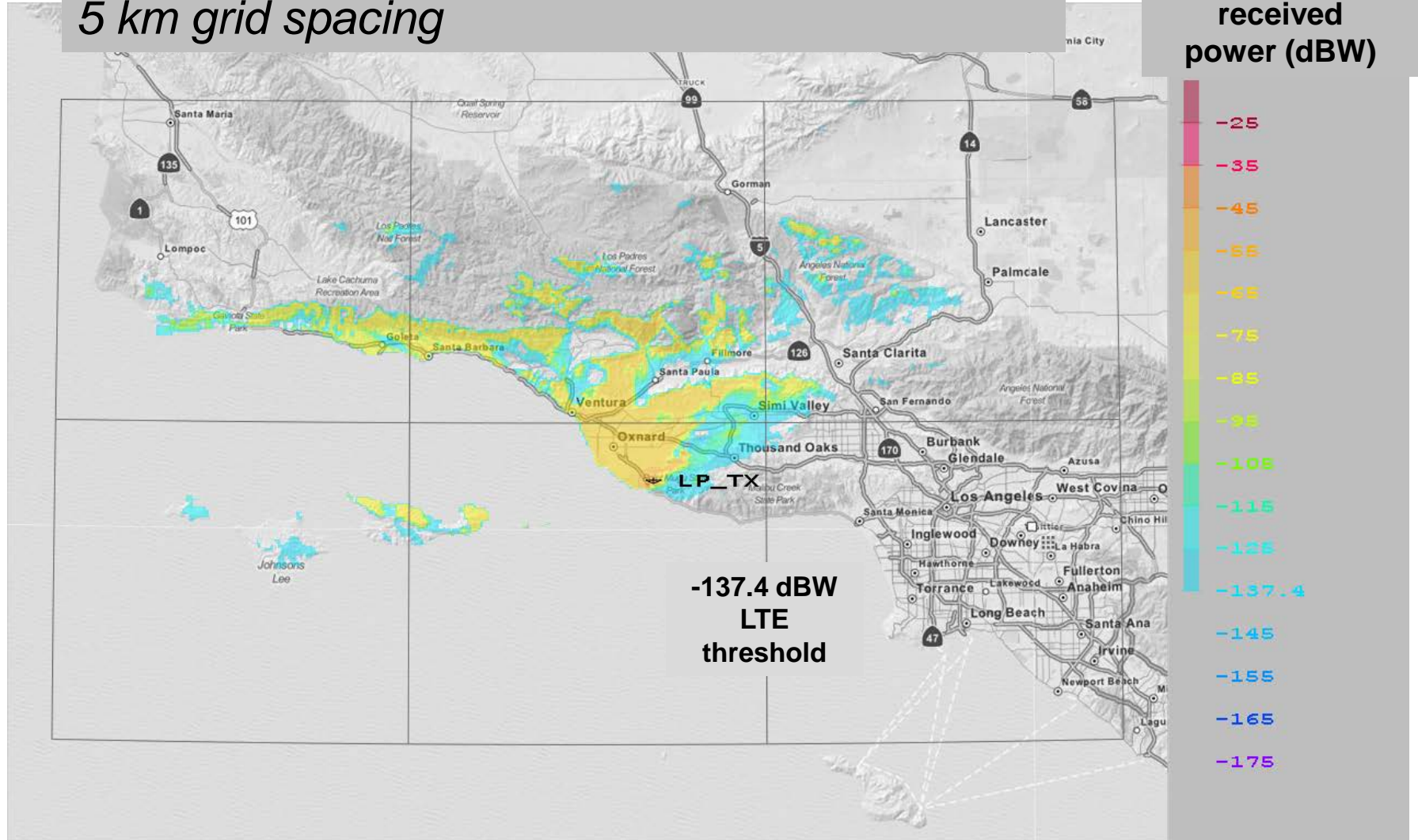
LTE base station
received
power (dBW)



LP, CA Radiated Power With Natural Terrain in Gray Indicating Power Below Threshold

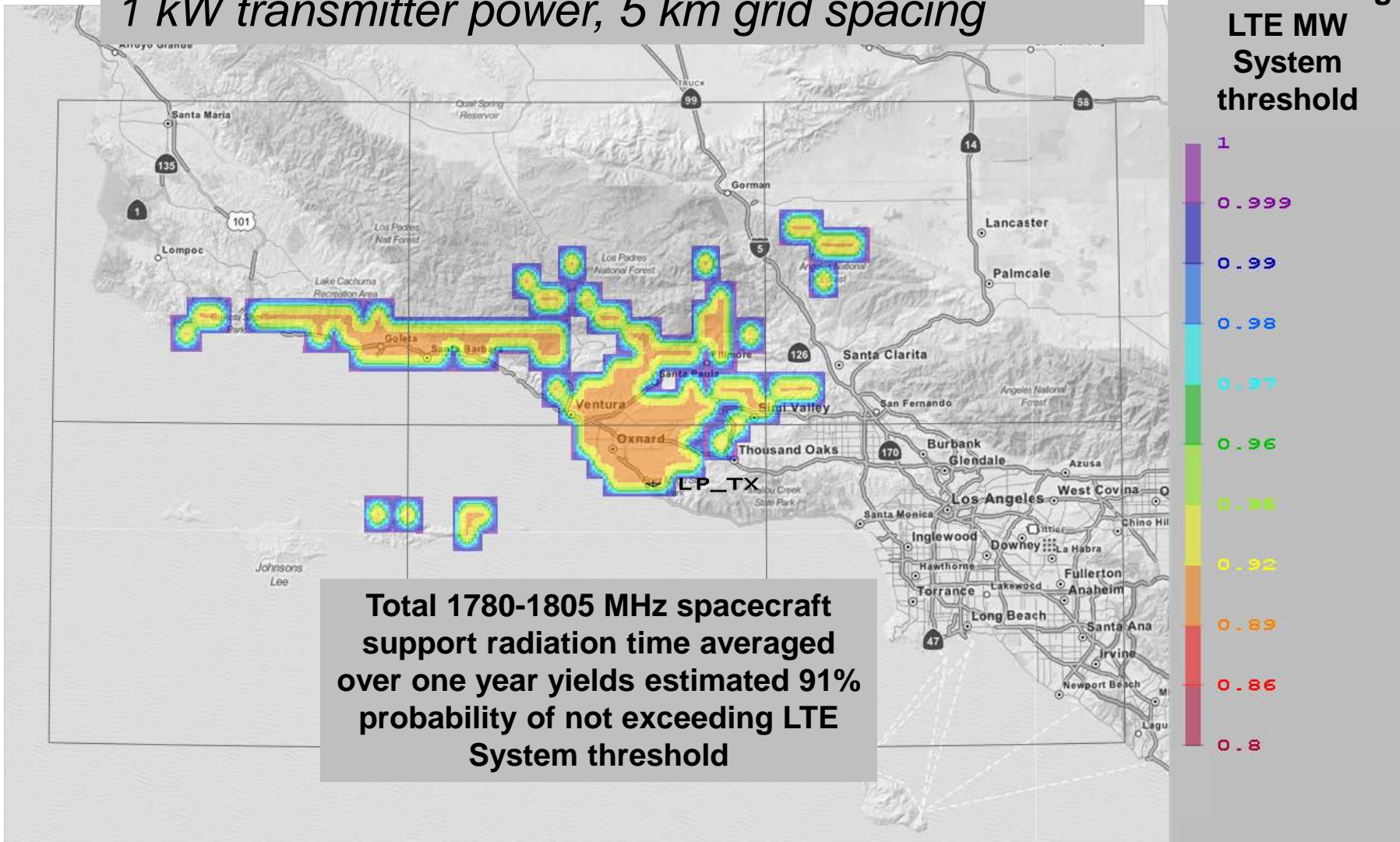
*1 kW transmitter power, with 20 dB attenuation
5 km grid spacing*

LTE base station
received
power (dBW)



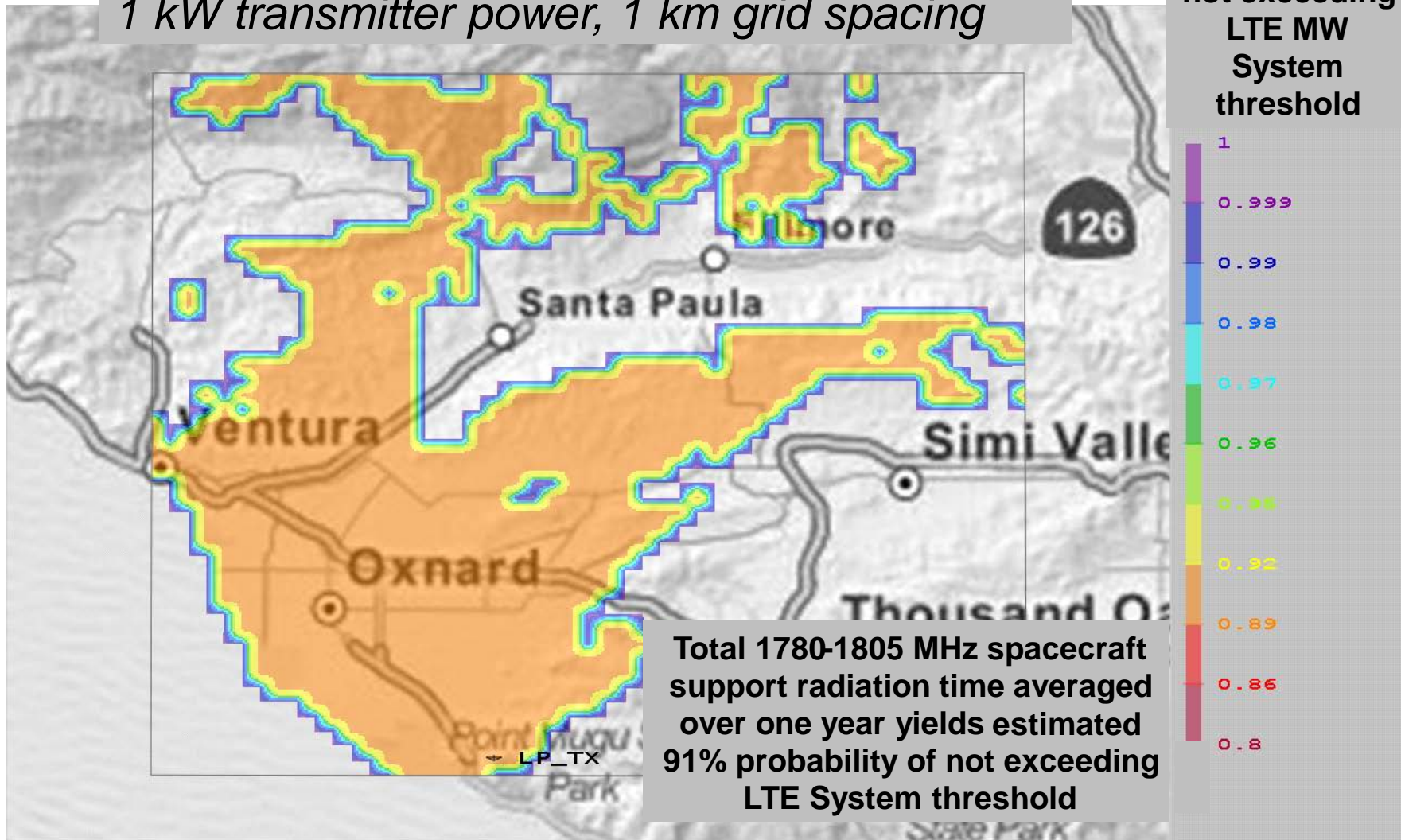
LP, CA LTE System Threshold Exceedance, 1780-1805 MHz

1 kW transmitter power, 5 km grid spacing



LP, CA LTE System Threshold Exceedance, 1780-1805 MHz

1 kW transmitter power, 1 km grid spacing



Appendix B – Technical Rationale

- **The following topics are elaborated in this Appendix**
 - *ITM Parameters*
 - *Transmitter and Receiver Parameter Choices*
 - *RFI Overlap for Two Antennas Operating at a Site*
 - *Mathematical definition of Threshold Non-Exceedance Calculation*

Irregular Terrain Model (ITM)

Input Parameter Value Choices

- Electrical Parameters

- 1 - Polarization
 - 1-vertical
 - 0-horizontal
- 15 - Dielectric constant of ground
 - 4-poor ground
 - 15-average ground
 - 25-good ground
 - 81-fresh/sea water
- 0.005 - Conductivity of ground
 - 0.001-poor ground
 - 0.005-average ground
 - 0.02-good ground
 - 0.01-fresh water
 - 5.00-sea water

- Regional and Temporal Parameters

- 50 - # of Reliability/Time statistic
- 50 - # of Confidence/Location statistic
- 2 - Radio climate
 - 1-Equatorial
 - 2-Continental subtropical
 - 3-Maritime tropical
 - 4-Desert
 - 5-Continental Temperate
 - 6-Maritime temperate, over land
 - 7-Maritime temperate, over sea
- 301 - Surface Refractivity
 - 280 - Desert (Sahara)
 - 301 - Continental Temperate
 - 320 - Continental Subtropical (Sudan)
 - 350 - Maritime Temperate, Over Sea
 - 360 - Equatorial (Congo)

Transmitter and Receiver Parameter Choices

Transmitter Frequency (MHz)	1762	Receiver 3dB Beamwidth (az) (deg)	70
Transmitter Power (dBm)	60	Receiver Antenna Gain at Horizon (dBi)	18.0
Peak Antenna Gain (dBi)	*	Receiver Ref Sensitivity (dBm)	-101.50
Antenna Gain **@ Horizon (dBi)	16	Receiver Interference @ 1 dB desense (dBm)	-107.37
(Offset of Antenna Mainbeam +3 deg elev)		ReceiverInterference @ 3 dB desense (dBm)	-101.50
EIRP @ Horizion (dBm)	*	ReceiverSensitivity (1 dB desense, dBW)	-207.94
Transmitter Antenna Height (m)	30	ReceiverSensitivity (3 dB desense, dBW)	-202.07
ReceiverAntenna Height (m)	30		
Receiver Antenna Down tilt (deg)	3		
Receiver 3dB Beamwidth (el) (deg)	10		

* Site Dependent

**Reference NTIA TM 13-489 Section 6.3.1.3 f (Ref.5)

RFI Overlap for 2 Antennas

- Radiation time for each antenna pointing angle was delivered as a sum of the time radiated in that direction by antenna A and the time radiated in that direction by antenna B
 - *This causes some radiation time and thus some threshold exceedance time to be double-counted*
- The overlapping threshold exceedance time can be described as:

$$P(\text{RFI Overlap}) = P(\text{ant A on AND ant A exceeding threshold AND ant B on AND ant B exceeding threshold})$$

- This double-counted time was calculated (as shown on the next slide) and removed from the threshold exceedance times

RFI Overlap for 2 Antennas Calculation

- Assuming independence between antenna A and antenna B,

$$P(RFI \text{ Overlap}) = P(\text{ant A on}) * P(\text{ant A exceeds threshold} \mid \text{ant A on}) * \\ P(\text{ant B on}) * P(\text{ant B exceeds threshold} \mid \text{ant B on})$$

- Assuming the same radiation time for and received power distribution from the 2 antennas,

$$P(\text{ant A on}) = P(\text{ant B on}) \text{ and}$$

$$P(\text{ant A exceeds threshold} \mid \text{ant A On}) = P(\text{ant B exceeds threshold} \mid \text{ant B On})$$

- $P(RFI \text{ Overlap}) = P(\text{ant A on})^2 * P(\text{ant A exceeds threshold} \mid \text{ant A On})^2$
 $= [(Radiate \% / 2) * P(\text{ant A exceeds threshold} \mid \text{ant A On})]^2$

$$= (Threshold \text{ Exceedance} \% / 2)^2$$

- $(Threshold \text{ Exceedance} \% / 2)^2$ is the correction factor that was used to remove double-counted threshold exceedance times from our calculations

Non-Exceedance Calculations

- **Non-Exceedance Calculation**

$$P(NE) = \sum_{i=1}^n \sum_{j=1}^m P(NE | [Az_i \cap El_j]) P(Az_i \cap El_j) + [1 - \sum_{i=1}^n \sum_{j=1}^m P(Az_i \cap El_j)]$$

where $P(NE)$ = Probability of Non-Exceedance

(equation excludes correction factor discussed earlier)

- **Without Variance**

$P(NE | [Az_i \cap El_j])$ is strictly 1 or 0 following the condition

$$P(NE | [Az_i \cap El_j]) = \begin{cases} 1 & \text{if } MeanRxPwr < Threshold \\ 0 & \text{if } MeanRxPwr \geq Threshold \end{cases}$$

- **With Variance**

$P(NE | [Az_i \cap El_j])$ is based on the Q-function because received power for a given Az/EI pointing direction is log normal and follows the condition

$$P(NE | [Az_i \cap El_j]) = 1 - Q\left(\frac{(Threshold - MeanRxPwr)}{\sigma}\right)$$